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# In harm's way: Climate security vulnerability in Asia ☆

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ABSTRACT

Asian countries have among the highest numbers of people exposed to the impacts of climate-related hazards and, thus, at greatest risk of mass death. Floods, droughts, and storms have always tested civilian governments and international humanitarian aid agencies. However, climate change threatens to make the problem worse by increasing the intensity and possibly the frequency of climate-related hazards. Humanitarian emergencies potentially upend and reverse progress on development priorities, making improved spatial awareness of likely hot spots a priority for adaptation and preparedness. This article presents the findings of the effort to map sub-national "climate security vulnerability" in 11 countries in South and Southeast Asia. Climate security vulnerability is defined as areas where large numbers of people are at risk of death due to exposure to climate-related hazards and the follow-on consequences of exposure, including but not limited to conflict. The Asian Climate Security Vulnerability Model Version 1 (ACSV V1) found that Bangladesh, parts of southern and western Myanmar (the Ayeyarwady region and Rakhine state), and parts of southern and northwest Pakistan (Sindh and Khyber Pakhtunkhwa provinces) were the most vulnerable from a climate security perspective. In terms of absolute numbers, the largest numbers of people who are exposed to climate hazards are in India followed by Bangladesh. Model results are compared with a geo-referenced version of the EM-DAT Disaster Database and by creating alternative model specifications informed by a survey of 18 regional experts.



In May 2008, a major cyclone devastated the Ayeyarwady Delta in Myanmar and left 700,000 homeless. Three quarters of the delta's livestock were killed. Half of the fishing fleet sank, and a million acres of rice paddies were inundated with saltwater (The New York Times, 2009). Myanmar's authoritarian regime did not request nor permit significant foreign aid. The U.S. Navy, having made fifteen unsuccessful attempts to receive authorization to deliver aid, ultimately ordered its ships to depart in early June (The New York Times, 2008). In the end, some 140,000 people died (Zarni & Taneja, 2015).

In July 2010, Pakistan faced its own climate-related emergency, with floods in the Indus River basin affecting as many as 20 million people. Like Myanmar, Pakistan's government was criticized for its slow response to the crisis, its president blamed for proceeding with an overseas European trip as the floods unfolded (Shah, 2010). Ultimately, 2000 people lost their lives and 11 million were left homeless. However, unlike Myanmar, the Pakistani government was more open to relief efforts. Donors ultimately pledged in excess of $2.5 billion to help Pakistan respond to the floods (UNOCHA, 2016).

In 1999, a devastating category five cyclone smashed into Odisha state in eastern India on the Bay of Bengal. 10,000 people were killed. In 2013, another category five hurricane struck the same state. In this instance, 50 people died, as the country evacuated more than 500,000 people from low-lying areas, the largest such evacuation in more than 23 years (Press Trust of India, 2013). While donors like the U.S. Agency for International Development (USAID) worked with India on early warning systems and disaster preparedness, India did not rely much on disaster aid for preparedness or recovery (Konyndyk, 2013).

As a densely populated region with many people living along rivers and low-elevation coastal zones, Asia has among the highest numbers of people exposed to the impacts of climate-related hazards in the world (IPCC, 2012, 240, 254). By one count, as many as 17 of 26 megacities – cities with populations in excess of ten

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million people – are located in Asia (Cox, 2012). While floods, droughts, and storms have always tested civilian governments and international humanitarian aid agencies, climate change threatens to make the problem worse by increasing the intensity and possibly the frequency of climate-related hazards (IPCC, 2012). From 2000 to 2012, of the 2.74 billion people killed and affected by climate-related disasters worldwide,[1] 89% were located in Southeast, Southern, and Eastern Asia.[2]

However, as the examples that opened this article show, whether exposure to climate hazards translates into large-scale loss of life in specific places hinges crucially on other social factors and the relationship between citizens and their governments. Some governments in the region such as India and Bangladesh have over time improved their capacity and willingness to protect their citizens, at least from the catastrophic impacts of such hazards. Other governments, such as Myanmar and Pakistan, by contrast, have been less able and/or less responsive to climate-related hazards. Climate-related humanitarian emergencies have the potential to upend and reverse progress on development priorities. At a time of scarce resources for humanitarian and development assistance, climate-related disasters impose major demands on governments and aid providers, forcing them to put off long-run investments to deal with unfolding emergencies. While there is a vigorous academic debate about whether disasters affect long-run country GDP, unnecessary suffering and death are not positive development outcomes (Shabnam, 2014; Bergholt & Lujala, 2012; Cavallo, Galiani, Noy, & Pantano, 2013). Even if countries historically have rebounded after disasters, climate change may worsen their future economic impact.

The effects of climate-related emergencies are also more than humanitarian and development challenges. An emergent discussion in policy circles and among academics links climate change and security (Barnett, 2003; Salehyan, 2008; Gleditsch, 2012; Scheffran, Brzoska, Jasmin Kominek, Link, & Schilling, 2012; Salehyan, 2014). While there are diverse ways climate change can affect security outcomes and contested understandings of security, the loss of life from exposure to extreme weather events is identified as a core security concern in the IPCC Fifth Assessment Report chapter on human security (Adger et al., 2014, 762). Climate change may also indirectly lead to loss-of-life by contributing to conflict, though this relationship, as the IPCC notes, remains "contested." That said, the IPCC concluded that climate change likely has an impact on factors such as low per capita incomes, economic contraction, and weak state institutions that are strongly associated with the incidence of violent conflict (Adger et al., 2014, 758).

Where will the consequences of climate change be concentrated in Asia? Current data availability makes this a difficult question to answer with geographic precision and high confidence. Asia is a diverse and large region; thus, the impacts are likely to vary significantly by location. Regional projections of future climate change impacts are increasingly fine-grained, but there is still much scientific uncertainty about specific effects in particular places.

To the extent that early warning and vulnerability analysis can help limit the need for expensive emergency mobilization, improved spatial awareness of likely hot spots can help prioritize climate adaptation and disaster preparedness (Barrett, 2014). However, while vulnerability mapping holds some promise as a tool for decision-makers, it is not without complications, given the heterogeneity of definitions of vulnerability and approaches to modeling it (Preston, Yuen, & Westaway, 2011; Cardona et al., 2012). As de Sherbinin notes, the assumptions that go into modeling risk reifying concepts like vulnerability and resilience at the expense of local contextual knowledge and power relations (de Sherbinin, 2014, 34; see also Ribot, 2014).

These concerns notwithstanding, this article provides a portrait of regional vulnerabilities or hot spots by mapping sub-national "climate security vulnerability" for 11 countries in South and Southeast Asia. Study countries include six countries in South Asia – Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka – and five countries in Southeast Asia – Cambodia, Laos, Myanmar, Thailand, and Vietnam.[3] Climate security vulnerability is defined as the risk in a particular location that large numbers of people could die from either direct exposure to a natural hazard or the follow-on consequences of instability and conflict that the hazard might generate (Busby, Smith, & Krishnan, 2014, Busby, Smith, White, & Strange 2013).

To map hot spots, physical, demographic, social, and governance indicators are combined in a composite index, the Asian Climate Security Vulnerability Model Version 1 (ACSV V1). Our approach is anchored at the intersection of studies of development, disasters, and security. We emphasize security, distinguishing this model from other accounts of climate vulnerability that tend to focus on livelihoods.

The ACSV V1 findings suggest that much of Bangladesh, parts of southern and western Myanmar (the Ayeyarwady region and Rakhine state), and parts of southern and northwest Pakistan (Sindh and Khyber Pakhtunkhwa) are the most vulnerable locations from a climate security perspective. In terms of absolute numbers, the largest numbers of people who are exposed to climate hazards are in India followed by Bangladesh. The article subjects the model to sensitivity tests (1) by comparing the results with work by Germanwatch and a geo-referenced version of the EM-DAT International Disaster Database, (2) by providing alternative specifications of the model, and (3) by surveying 18 regional experts and building alternative maps based on their responses.

This article unfolds in six parts. In the first, we explain the concept of climate security vulnerability and anchor our approach in the wider literature. In the second, we discuss the methodology. In the third, we present our results. In the fourth section, we compare our results to work by Germanwatch and a geo-referenced version of the EM-DAT International Disaster Database. In the fifth, we present sensitivity analysis of our model using different functional forms and model weights drawn from a survey of eighteen regional experts. In the final section, we discuss our research agenda going forward.

## 1. Defining climate security vulnerability

There is a rich literature on vulnerability and climate change, but there is no unified definition of vulnerability across different disciplines, making comparisons between studies animated by different assumptions and definitions problematic (Füssel, 2007; IPCC Working Group II Report, 2014, 6; IPCC, 2012; O'Brien, Eriksen, Nygaard, & Schjolden, 2007; Cutter et al., 2008). Consequently, researchers must be clear about their meaning of vulnerability and its operationalization.

[1] Climate-related disasters include storms, floods, wet mass movements, extreme temperatures, droughts, and wildfires (CRED, 2012). The average was 228 million a year over this time period.

[2] These numbers are estimates derived from the EM-DAT International Disaster Database, the main dataset that compiles information and statistics on disasters. Southern Asia encompasses Afghanistan, Bhutan, India, Iran, Maldives, Nepal, Pakistan, and Sri Lanka. Southeast Asia includes Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, and Vietnam. Eastern Asia thus encompasses China, Hong Kong, Macao, North Korea, Japan, Mongolia, and South Korea. United Nations Statistics Division, http://unstats.un.org/unsd/methods/m49/m49regin.htm.

[3] The choice of these specific Asian countries was determined by the funder of the research.

The IPCC defines vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes."[4] Another IPCC report on extreme events and climate change offers a slightly different definition: "Vulnerability refers to the propensity of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events" (Cardona et al., 2012, 69). Adger offers a third definition: "Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger, 2006, 268).

The 2012 IPCC report identifies four understandings of vulnerability, (1) one rooted in political economy that emphasizes social causes over physical ones, (2) a social ecology perspective that focuses on how physical and social dimensions are coupled; (3) a holistic approach that incorporates exposure, susceptibility, and societal response capacities, and finally (4) a disaster risk management approach that sees risk as a function of exposure and vulnerability, with vulnerability reflecting the social aspects of risk (Cardona et al., 2012, 71; Alexander, 2009; Burg, 2008).

Adger collapses categories further and distinguishes between vulnerability as a "lack of entitlements" and another that focuses on "vulnerability to natural hazards" (Adger, 2006, 270; for a similar formulation, see Füssel & Klein, 2006; Pricope, Pardo, & López-Carr, 2014). Cutter similarly distinguishes between vulnerability as a social condition and as exposure to hazards (Cutter, 2003, 1996). In different ways, both comment on the aim of contemporary research to reconcile these definitions by integrating social and physical understandings of vulnerability, with Cutter's work focusing on place-based vulnerability and the related concept of resilience (Cutter et al., 2008; Cutter, Ash, & Emrich, 2014).

Historical distinctions in approaches have given way to the recognition that vulnerability consists of "multiple stressors and multiple pathways" (Adger, 2006, 268).[5] Thus, the IPCC in their conceptualization of vulnerability combines three dimensions, exposure to hazards, the sensitivity of the system to hazards, and adaptive capacity.[6] Like the IPCC, we recognize that multiple stressors drive vulnerability. We are mainly focused on a more limited aspect of vulnerability to climate extremes, which we refer to as "climate security vulnerability." In our conceptualization, climate security vulnerability reflects the likelihood of large numbers of human fatalities as a result of direct exposure to climate hazards or the proximate consequences of conflict and instability that follow in the aftermath of exposure (Busby et al., 2014b, Busby et al., 2013). As we discuss further in Part 2, we model the compounding effects of four baskets of indicators: (1) the occurrence of physical hazards; (2) population density; (3) household and community resilience; and (4) governance. The first two categories capture human exposure to climate hazards. The third category captures sensitivity while the last focuses on the willingness and ability to respond or adapt.

Much of the literature on climate and security focuses narrowly on whether climate change contributes to conflict. We see the field of security studies to be broader than this. Events such as humanitarian emergencies are arguably security concerns since they frequently require military mobilization in response and the number of affected can be comparable to those affected by armed conflict. Though the effects of climate change and related disasters on conflict are contested (Adger et al., 2014; Bergholt & Lujala, 2012; Slettebak, 2012; Nel & Righarts, 2008), its accelerative effects on conflict and instability are plausible even if the scope conditions have yet to be fully understood.

While some have argued for an expanded concept of human security that encompasses any threats to human well-being, we worry, like Roland Paris, about the risks of conceptual stretching if security deviates too much from the conventional understanding of protecting states from external attacks (Paris, 2001, 2004; for an application of human security to South Asia, see Najam, 2003b, 2003a). Like Richard Ullman, we see insecurity more in terms of actions or events that threaten "to drastically and over a relatively brief span of time to degrade the quality of life of the inhabitants of a state" (Ullman 1983, 133). Large-scale loss of life is the ultimate degradation of the quality of life. Our work is thus pitched somewhere between human security and security as the study of conflict.[7] Space forbids a more lengthy treatment of the boundaries of security studies, but we have explored these issues more extensively in (Busby, 2008, Busby et al., 2013).

Our security focus distinguishes it from those that focus on livelihoods and declining sources of income and assets at the household, community, or regional level. Other climate-related vulnerability studies focus on threats to food security (Krishnamurthy, Lewis, & Choularton, 2014), livelihoods and/or economic growth (DARA, 2012; ND-GAIN, 2013; Dabla-Norris & Bal Gündüz, 2014; Ward & Shively, 2012; Islam, Monirul, Hubacek, & Paavola, 2014; Ahmed, Diffenbaugh, & Hertel, 2009; McCubbin, Smit, & Pearce, 2015; Adger, 1999), evaluate specific hazards such as droughts (Carrão, Naumann, & Barbosa, 2016; Naumann, Barbosa, Garrote, Iglesias, & Vogt, 2014), floods (Brouwer, Akter, Brander, & Haque, 2007), ecozones such as drylands (Sietz, Lüdeke, & Walther, 2011), groups such as farmers and livestock keepers (Thornton et al., 2006) and pastoralists (Dong, Liu, & Wen, 2016), or sub-regions such as rural areas (Eakin, 2005). Where those studies mainly focus on the effects on income and assets, we are primarily interested in whether exposure to climate hazards leads to large-scale loss of life.

Climate security vulnerability and disasters are closely related conceptually. The literature on disasters has recognized the term "natural disaster" is a misnomer (Wisner, Blaikie, Cannon, & Davis, 2004; Basher & Briceño, 2005; Kelman, Gaillard, Lewis, & Mercer, 2016). Large-scale loss of life is not natural. While climate-related physical hazards such as cyclones endanger the lives of millions, large numbers of people are not destined to die merely as a result of exposure. In some situations, resilient communities and capable governments are able to prevent exposure to a natural hazard from becoming a *disaster*, a situation where large impacts on the local population occur. However, in other instances, an absence of risk reduction and preparedness investments makes communities vulnerable, with civilian agencies potentially overwhelmed in the event of a hazard event. In other circumstances, governments fail in their ability or willingness to assist communities. Disasters and humanitarian emergencies therefore are one indicator of climate security consequences, but

[4] Exposure reflects the character, magnitude, and rate of climate variation. Sensitivity is understood as how the climate system will respond to a given amount of radiative forcing from greenhouse gases (IPCC, 2007b). Finally, adaptive capacity reflects "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC, 2007a, Chapter 2).

[5] For discussion of those distinctions, see (Kelly and Adger 2000; K. L. O'Brien et al. 2007).

[6] Exposure reflects the character, magnitude, and rate of climate variation. Sensitivity is understood as how the climate system will respond to a given amount of radiative forcing from greenhouse gases (IPCC 2007b). Finally, adaptive capacity reflects "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2007a, Chapter 2).

[7] We do not however seek to model the disease environment itself such as risks of malaria or other vector-born diseases that may be affected by climate hazards.

as we are also interested in the follow-on consequences of hazard exposure on political stability and violence, disasters are not the only security concerns of interest.

The recognition that physical exposure alone does not determine vulnerability underscores the importance of governance (see also Najam, 2003b, 2003a). This is not a new point. Amartya Sen's classic work on famine entitlement failure captures the sense that there can be plentiful amounts of food but some populations may be deprived of access because they lack the resources to buy food and, importantly, support from government to compensate for lost earnings or purchasing power (Sen, 1981; Ribot, 2014). Sen's observation that famines do not happen in democracies, where elected leaders tend to respond to voters' needs, underscores the significance we place on governance. As we detail in Part 2, governance in our model is an entirely separate basket of indicators, which encompasses different dimensions including political stability, global integration, voice and accountability, and government effectiveness. Political exclusion as a driver of climate-conflict risks is central to the best work in the environmental security literature (von Uexkull et al., 2016; Hendrix, 2016; Kahl, 2006).

The clearest connection (and perhaps the shortest causal chain) between natural hazards and mortality risk is visible after swift onset hazards such as cyclones, where the physical consequences of extreme weather events can lead to large-scale loss of life in hours or days. However, even those moments represent failures of national level governance and at the household and community level to prepare. Better planning, climate resilient infrastructure, early warning systems, stronger emergency response mechanisms, and other measures can ensure that exposure to a hazard does not translate into dire consequences.

For slow onset hazards such as droughts, the risks of large-scale loss of life may unfold over a longer period of time and result after families lose sources of income, savings, and assets such as livestock. As the climate and security literature has recognized, economic contraction, particularly of food production, that comes about because of climate hazards is thought to be one of the most important indirect mechanisms likely to lead to conflict, though as yet remains understudied (Koubi, Bernauer, Kalbhenn, & Spilker, 2012; Meierding, 2013; Hendrix & Brinkman, 2013). We recognize that capturing those processes that unfold are longer periods of time in a static snapshot of vulnerability is challenging, and our modeling is a necessary simplification. Since subnational georeferenced measures of economic well-being are poorly developed, we discuss this issue more fully in our section on household and community resilience in Part 2.

Vulnerability and resilience are often used as antonyms, and there is a vigorous debate about the relationship between the two and their meanings (Miller et al., 2010; Kelman et al., 2016; Weichselgartner & Kelman, 2015; Gallopín, 2006; Cannon & Müller-Mahn, 2010; Walsh-Dilley, Wolford, & McCarthy, 2016). Resilience is sometimes seen as a broader phenomenon than vulnerability and sometimes as a subcomponent of vulnerability (Berkes, 2007). The concept of resilience has its origins in biological and ecological systems analysis, but scholars caution that application to human systems necessarily needs to incorporate social and political dimensions (Matin, Forrester, & Ensor, 2018; Berkes & Ross, 2013; Ross & Berkes, 2014; Folke, Hahn, Olsson, & Norberg, 2005). Resilience is often defined as the ability of communities to bounce back from exposure to a negative shock. However, even the 'bounce back' component of resilience has been critiqued. What if the *ex-ante status quo* was undesirable? Perhaps resilience should be conceptualized as the transformational capability for communities to "bounce forward" rather than bounce back from adversity (Manyena, 2006; "Disaster Resilience: A Bounce Back or Bounce Forward Ability?" 2011)? While the word resilience often reflects an actor's ability to withstand and rebound from adversity (for a discussion, see Barnett, 2001), we use the term in our modeling effort below in a more limited, specific way to reference household level resources and access to services.

## 2. Modeling climate security vulnerability

Many global vulnerability models rank countries rather than provide sub-national assessments (Wheeler, 2011; Füssel, 2010; Brooks, Adger, & Kelly, 2005). Some assessments, such as those by USAID's Famine Early Warning Systems Network, are dynamic and seasonally updated but more narrow in scope (FEWSNET) (USAID n.d.). We developed a methodology for locating *climate security vulnerability* that is geographically disaggregated and broad in scope. To identify the places most likely to suffer from climate change over the next couple of decades, we capture a snapshot of long-term or what Burg called chronic vulnerability (Burg, 2008). Our work is a sub-national portrait of relative vulnerability within a region, where all points on the map are ranked relative to the rest of the region.

Adger writes of the challenges of developing vulnerability metrics: "Measurement of vulnerability must therefore reflect social processes as well as material outcomes within systems that appear complicated and with many linkages that are difficult to pin down. Vulnerability is, therefore, not easily reduced to a single metric and is not easily quantifiable" (Adger, 2006, 274). That said, the attraction of modeling vulnerability persists. As Preston et al. argue: "Understanding the geography of climate change vulnerability has the potential to assist with risk and disaster management, reducing exposure of human and ecological assets, anticipating future 'hot spots' for adverse impacts, and identifying particularly vulnerable populations that may be prioritized for intervention" (Preston, et al., 2011, 179; see also Smit & Wandel, 2006).

Scholars have sought to integrate the physical and social dimensions of vulnerability through innovative methods. O'Brien et al. for example, combine two stressors, globalization and climate change, to assess district-level agricultural vulnerability in India (O'Brien et al., 2004). Yusuf and Francisco bring in multiple climate hazards, sensitivity (a combination of population and protected areas), and various indicators of adaptive capacity to generate an overall vulnerability index for Southeast Asia. Interestingly, for their adaptive capacity sub-index, they use weights derived from an expert survey (Yusuf & Francisco, 2009).

Adger warns that despite these advances, we have to treat the results of vulnerability indices with some skepticism since we are reliant on proxy indicators and cannot measure vulnerability or the processes that contribute to it directly: "Hence a leap of faith is required between vulnerability of a key variable (whether physical or social) and other elements such as ecosystem services or well-being. Unless the variable and causal links are well established, the relationship may not hold" (Adger, 2006, 276).

This means that indicators used in vulnerability assessments ought to be validated using observational data. However, as Preston et al. note, correlations between climate change vulnerability assessments and natural disaster mortality, for example, have often been poor and/or data necessary to validate models are not available (Preston, et al., 2011, 192). Thus, it is difficult to know if models have any predictive value to meaningfully inform practice, placing greater pressure on researchers to be transparent about their assumptions and deductive logic. As Preston et al. note, few vulnerability assessments address uncertainty, which can mean elegant maps potentially convey false precision. One way to address this problem is through alternative scenarios to assess

the sensitivity of models to different assumptions (Preston, et al., 2011, 191).

Ribot raises a different concern, worrying that efforts to incorporate social variables such as capacity and poverty into vulnerability models might fail to assess "why capacity is lacking, assets are inadequate or social protections are absent or fail" (Ribot, 2014, 667). Ribot calls for understanding governance arrangements and the reasons entitlements are lacking in the first place. We agree that it is vitally important to include measures of governance in any sub-national assessment of vulnerability. While it is challenging to map variations in governance at the sub-national level, we believe governance-related processes are critically important to capture in vulnerability assessments.

While the IPCC tripartite definition of vulnerability as the combination of exposure, sensitivity, and adaptive capacity is appealing, it relies on more abstract concepts that must still be operationalized using available, reliable, and comparable indicators. Approaches that have used it as a basis for vulnerability assessments sometimes select indicators that overlap, potentially raising the risk of double-counting. Brenkert and Malone's index for India, for example, includes a measure of population density in adaptive capacity and population at risk of floods from sea-level rise in sensitivity (Brenkert & Malone, 2005).

While we are committed to and see vulnerability as multi-dimensional, we chose to group and organize the processes differently than the IPCC into four baskets: physical exposure, population density, household and community resilience, and governance. Vulnerability extends beyond mere *physical exposure*. For large numbers of people to die, an area exposed to a physical hazard has to have a large or concentrated *population*. Both exposure and population are necessary to capture human exposure. However, whether people die depends in part on what resources they have to protect themselves at the *household and community level*. Finally, some natural hazards may exceed the capacity of communities to protect themselves so this further depends on whether their *governments* are willing and able to protect them in times of need.

We elaborate and defend the choice of specific indicators below, but the value of organizing these conceptually into four baskets allows us to sequentially show how vulnerability changes as you add a new dimension. Where do climate hazards occur? Where does that coincide with where people live? Do those people have the household and community resources to withstand or respond to the impacts of climate events? If that fails, is the national government able and willing to provide assistance or is it open to assistance from the international community?

Our model views climate security vulnerability as a function of physical exposure, population density, household and community resilience, and governance. Each basket save for population density is comprised of multiple indicators, about six to eight per basket.[8] In the final composite, each basket is equally weighted, though we also explore variations in the sensitivity analysis.

Data were derived from different data sources, with varying spatial resolutions and temporal coverage. The spatial resolution in the physical and population baskets are the most fine-grained, as small as one square kilometer for some indicators. The resolution becomes increasingly coarser for the household and governance baskets. Many of the household indicators are available at the first administrative unit, while governance metrics, save for one indicator of violence, are only available nationally (see Appendix Tables for a summary of indicators).[9]

With econometric work, one might develop empirically driven indicator weights and also inform the choice of the model's functional form. However, the varying time periods, spatial resolution, and sampling frames of these indicators makes econometric validation problematic, though we have tried with mixed results in previous research (Busby et al., 2013). For that reason, we have largely followed conventions in the field of composite indices that equally weight the indicators and use an additive functional form with each basket taking on a weight of 25% (OECD, 2005; Stapleton & Garrod, 2007).[10] Equal weights have the virtue of simplicity, though they raise questions about the internal validity of the resulting index. The comparison with EM-DAT data and the sensitivity analysis are intended to address these concerns.

We rely on national-level econometric studies as inspiration for the choice of many indicators, particularly for the household and governance baskets. In their 2005 piece constructing a vulnerability index that excluded physical factors, Brooks et al. identified eleven indicators that were statistically correlated with disaster mortality including (1) population with access to sanitation, (2) literacy rate of 15–24-year olds, (3) maternal mortality, (4) literacy rate, over 15 years, (5) calorific intake, (6) voice and accountability, (7) civil liberties, (8) political rights, (9) government effectiveness, (10) literacy ratio (female to male), and (11) life expectancy at birth (Adger et al., 2004; Brooks, Adger, & Kelly, 2005).

They chose these indicators as proxies in the construction of a national-level composite vulnerability index. Sub-national data availability constrained our choices at times, particularly for governance. Some indicators, like those for literacy, were highly correlated. In such cases, we opted to use only one (literacy rate of 15–24 year olds). Our rationale for such choices is further explained below.

We first developed a comprehensive map of sub-national geographic units in the region, drawing from diverse information sources.[11] Subsequently, we sourced, analyzed, and processed data for each indicator and basket. Each indicator was normalized on a common scale in terms of its percent rank. This allows us to capture the relative rank of a given geographic unit relative to the rest of the region.

### 2.1. Physical exposure

While recognizing that future climate change might alter the patterns of physical exposure, this research is based on historic indicators, the justification being that in the short-run, perhaps the best guide to future exposure is past exposure (for a similar approach, see Yusuf & Francisco, 2009). In other projects, we have collaborated with climate modelers to compare contemporary exposure to future projections (Busby, Cook, Vizy, Smith, & Bekalo, 2014a). One of the challenges of using regional climate models as inputs of future exposure is that their time horizons, until recently, were relatively too distant to helpfully inform decision-makers about contemporary policy. While more near-term climate models have been developed, some with the most near-term projections are still for 2050 (Cook & Vizy, 2012; Vizy & Cook, 2012). By then, we can expect considerable change in population, adaptive capacities, and governance, raising questions about how to combine present day social and demographic indicators with future climate projections. At the same time, projections of demographic change and social conditions could introduce considerable error into a process that is already critiqued for conveying false precision.

[8] More detailed information is available on the project website. See www.strausscenter.org/cepsamappingtool/buildingthemodel.

[9] More detailed methods are described here www.strausscenter.org/cepsamappingtool/buildingthemodel.

[10] For a survey of these methodological choices and issues, see (Angeon and Bates, 2015).

[11] These include the Global Administrative Areas (GADM) and the USAID Demographic and Health Surveys (DHS).

The physical exposure basket includes indicators for cyclones, floods, wildfires, and water scarcity. In addition, a digital elevation model captures areas at risk of coastal inundation from storm surge and sea level rise (see Appendix Table 1). The team chose these indicators of climate hazards based initially on data available from UNEP's Global Risk Data Platform, namely for wildfires, cyclones, and floods. While drought data is available through UNEP, we developed and refined two measures that more accurately reflected water variability and chronic aridity. These indicators, rainfall anomalies and chronic aridity, were developed using data from the Global Precipitation Climatology Centre. Finally, while cyclones capture some of the risks associated with coastal exposure, low-lying areas are also subject to sea-level rise and storm surge. We account for this risk with a digital elevation model. All indicators in this basket are weighted equally, except for the two measures of water scarcity that split the weight between them.

### 2.2. Population

Physical exposure alone does not equate to vulnerability. All else equal, policymakers likely care more about climate hazards that affect large numbers of people. While this imparts a bias to densely populated areas, the emphasis on understanding the risk of large-scale loss of life warrants this modeling choice. In the sensitivity analysis, we also mapped what vulnerability would look like excluding population.

Unlike the other baskets, this basket consists of a single population density layer generated with data from LandScan (LandScan, 2013). LandScan is a modeled dataset that seeks to measure "ambient" populations and is based on a variety of inputs such as road networks, elevation, slope, land use/land cover, and high resolution imagery (*see* Table 2 in the supplementary material).

### 2.3. Household and community resilience

Inspired by indicators identified by Brooks et al., we created a basket of social indicators, which we call household and community resilience. If readers object to the word "resilience," we encourage them to see this basket as a representation of the ability at the household and community-level to respond to extreme events and resources that can be marshaled in a crisis. We have conceptualized and operationalized resilience in terms of high attainment of social indicators and access to services and basic necessities (Brooks, Adger, & Kelly, 2005; see also Brück, d'Errico, & Pietrelli, Forthcoming; d'Errico & Di Giuseppe, 2018). In the face of exposure to climate-related hazards, the first line of defense for communities and households is the resources they have to protect themselves, proxied in our model by their (1) levels of education, (2) quality of health, (3) access to health services and (4) daily necessities.[12] All else equal, communities that are better educated, have better health conditions, and access to services are likely to fare better and recover faster in the event of exposure to natural hazards compared to others with lower levels of achievement or access.

We recognize that the indicators in our model do not reflect community-level organizational capacities, particularly the kind of social solidarity that is often critical in response to crisis situations (Folke et al., 2005). While an important critique, spatially comprehensive, geographically disaggregated indicators of this nature are not yet available, though there are important efforts to apply such insights at the household level in Kenya, Bangladesh, Ethiopia, Honduras, Uganda, the Philippines, and Gaza (Quandt, 2018; Smith & Frankenberger, 2018; Kuhl, 2018; d'Errico & Di Giuseppe, 2018; Shah, Angeles, & Harris, 2017; Brück et al., Forthcoming). Like Béné et al., we recognize the challenge of operationalizing resilience for more programmatic purposes (Béné, Chowdhury, Rashid, Dhali, & Jahan, 2017). Following Matin et al., we agree that theories have different explanatory power (Matin et al., 2018). Where many recent studies of resilience are intended to track household resilience and gauge the efficacy of development interventions at the local level, our aim is to capture a snapshot of resilience for larger geographic units to inform a wider region-wide assessment. Moreover, while many studies of household resilience focus on consumption smoothing and broader metrics of well-being, the Brooks et al. piece is most directly relevant to our approach because their dependent variable was disaster mortality. Our choices of household indicators were driven by their findings.

For each of the four sub-processes, the team identified two relevant indicators as proxies. These included literacy and school enrollment (education), infant mortality and life expectancy (quality of health), nurses and delivery in a health facility (access to health services), and underweight children and access to improved water sources (daily necessities) (see Table 3 in supplementary material*)*.

All but two of the eight indicators (number of nurses, life expectancy) in this basket are available at the subnational level. For many countries in the region, sub-national information could be calculated at the first administrative level using the USAID Demographic and Health Surveys (DHS) or the UNICEF Multiple Indicator Cluster Survey (MICS).

As Yohe and Tol note, education and health indicators are likely highly correlated with economic well-being (Yohe & Tol, 2002), but spatially disaggregated estimates of income are scarce, though there have been efforts to use lights at night as a proxy (see Noor, Alegana, Gething, Tatem, & Snow, 2008; Xie, Jean, Burke, Lobell, & Ermon, 2016). These show some potential but remain in the early stages of development.

### 2.4. Governance

Natural hazards may exceed the coping capacities of local communities, thus requiring government mobilization to help them in times of need. The intuition here is that states that are less willing or able to respond to climate hazards, particularly in areas with a history of violence, are more vulnerable to climate change. These insights are informed in part by the work of Acemoglu and Robinson, North and his collaborators, and Colin Kahl on the dangers of exclusive institutions that lead to unequal provision of government services, leaving some populations more vulnerable to hazards and also serving as a source of grievance for underserved areas (Acemoglu & Robinson, 2013; North, Wallis, & Weingast, 2009; North et al., 2012; Kahl, 2006).

The governance basket includes measures of state capacity, political responsiveness, global integration, and stability. These indicators get at the combination of the willingness and ability of governments to respond to their citizens' needs.

The team drew from national level indicators of government effectiveness, voice and accountability, two measures of political stability, and global integration to map regional governance. We were informed by the Brooks et al. study and their use of government capacity and voice and accountability that reflect on a state's capacity but also its responsiveness to the needs of the people (Brooks, Adger, & Kelly, 2005). Both of these indicators were drawn from World Bank data.

Countries that have experienced rounds of frequent political instability are also less likely to be able to respond to their populace in times of need. We developed two measures of political

[12] Our conceptualization of resilience has some parallels to the FAO-RIMA approach that includes four dimensions: Access to Basic Services, Assets, Adaptive Capacity, and Social Safety Nets.

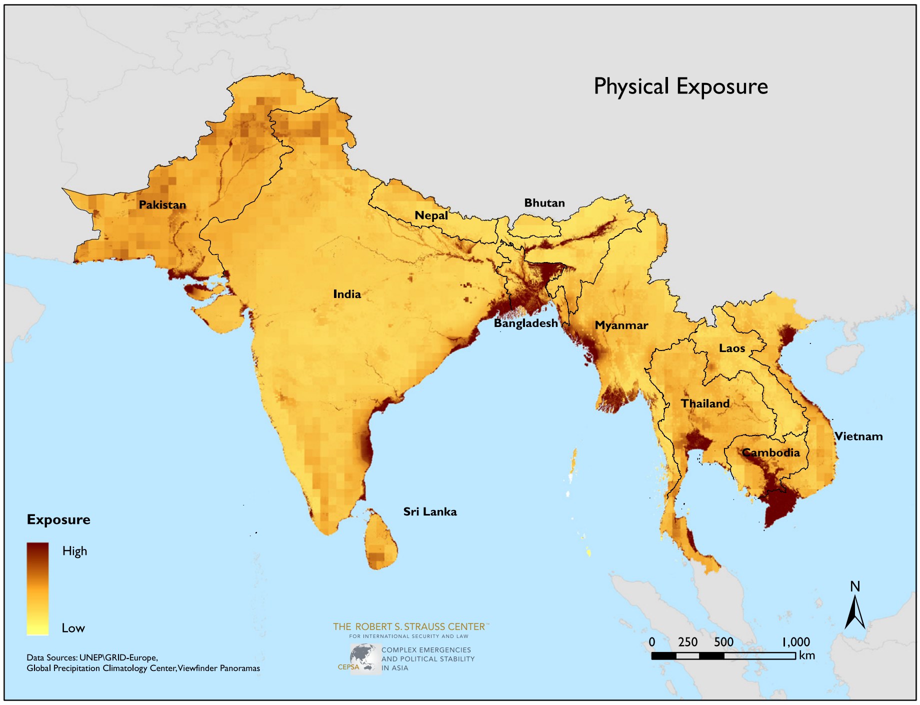


**Fig. 1.** Physical exposure.

instability using Polity IV data, one a measure of the polity variance in the previous ten years and another a measure of the length of time since the last major regime change. Since both indicators are slightly different methods to measure political stability, we split the weight between them.

Absent from our governance basket is regime type, which we see as imperfectly capturing processes of political exclusion and state capacity. By including measures of political stability, our model countenances the possibility that stable authoritarian regimes will be able to respond to their citizens' needs, though that might be counter-acted by their responsiveness to citizens' needs.

We also include a measure of global integration from the KOF Index of Globalization to capture the idea that countries that are weakly integrated into the global system, autarkic regimes in particular, may not be able or willing to tap into networks of global assistance in times of need. The Myanmar example with Cyclone Nargis in 2008 here is instructive. The only subnational measure in this basket is a measure of atrocities from the Political Instability Task Force (PITF) (see Table 4 in supplementary material).[13] Areas with a history of conflict may be less likely to receive assistance from the government in the wake of hazard exposure, either due to neglect or open hostility by the regime in power.

Bringing in state-level governance indicators and global integration acknowledges that local vulnerability is also affected by wider national and international relationships. We recognize that other sub-national governance processes are relevant, though this is, as yet, difficult to measure. We discuss research plans to address this in the conclusion (Fukuyama, 2013).

## 3. The results

In terms of physical exposure, the patterns in Fig. 1 show that low elevation coastal areas in Bangladesh and Myanmar are especially exposed to climate hazards. Cyclone risk coupled with low elevation coastal zones radiates from Odisha and West Bengal in India through Bangladesh to Rakhine State in Myanmar. Cyclone and low elevation coastal zone exposure also extend to Andhra Pradesh and Gujarat in southeastern and northwestern India respectively, and across the Sir Creek estuary to Sindh province in southwestern Pakistan. Flood exposure follows major river systems such as the Indus through Pakistan, the Ganges through India, the Brahmaputra in Bangladesh, and the Mekong in Cambodia. Negative rainfall anomalies are concentrated in central and northern Pakistan, Sri Lanka, Thailand, Cambodia, and southern Vietnam with chronic water scarcity concentrated in Sindh province in Pakistan. Southeast Asia has the most wildfires in the region with pockets in southern Myanmar, Thailand, northern Laos and Vietnam, and eastern Cambodia.

In terms of population density, Fig. 2 shows that South Asia is much more densely populated relative to Southeast Asia. Populated areas extend across the Indo-Gangetic plain at the base of the Himalayas, encompassing nearly all of Bangladesh and eastern India (including West Bengal and the city of Kolkata) across to the Indian states of Uttar Pradesh and Delhi and the Punjabs of western India and eastern Pakistan. Other notable areas include Kerala, a coastal southwestern state of India as well as sites around major cities including Colombo in Sri Lanka, Hanoi (Vietnam), and Bangkok (Thailand).

As for household and community resilience, we find that much of Pakistan and Laos were among the least resilient in the region as well as several parts of Myanmar (Ayeyarwady, Rakhine, Shan, and Chin states), one area in Cambodia (Takéo province), as well as much of Bhutan and Bangladesh, and two states in India (Bihar, Jharkhand) (see Fig. 3).

[13] The team has also experimented with conflict data from the Armed Conflict and Location Event Database, which have been extended to cover this region and for which conflict event data is currently available from January 2015 onwards. Contact the team for results.

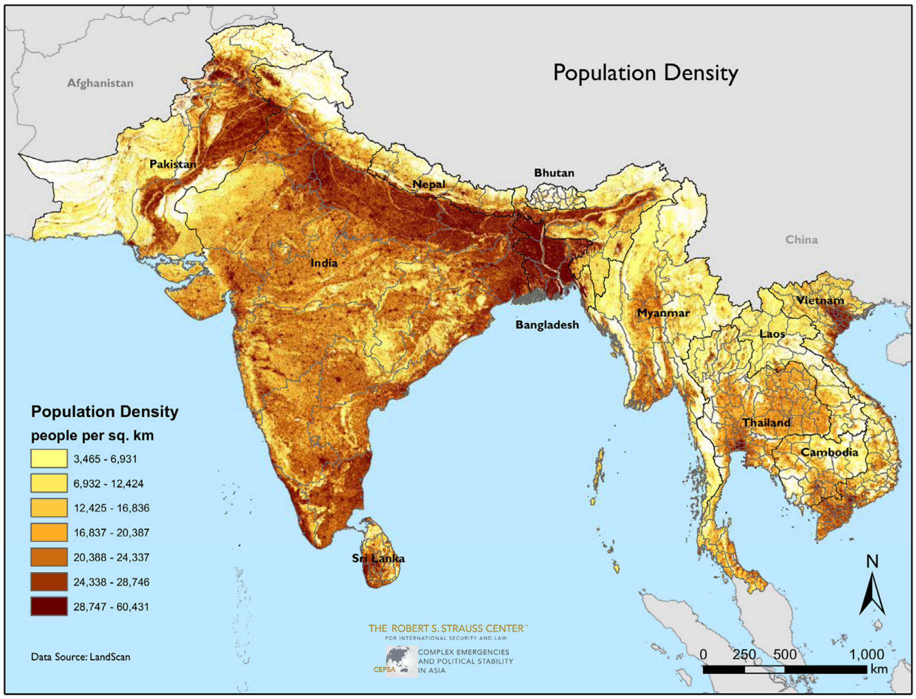


**Fig. 2.** Population density.

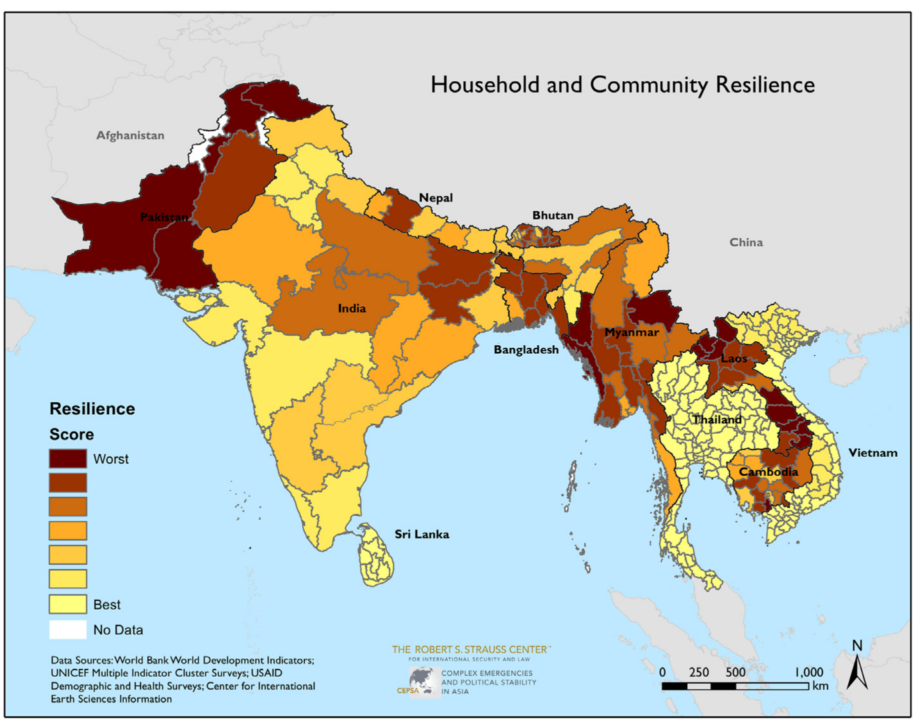


**Fig. 3.** Household and community resilience.

We find that Myanmar, Laos, and Nepal had the worst governance in the region followed by pockets in Pakistan (namely, in the north of the country in Khyber Pakhtunkhwa). Thailand (notwithstanding recent challenges) and Bhutan have the best governance scores in the region (see Fig. 4).

Combining these four layers yields a composite map of relative vulnerability in the eleven countries of South and Southeast Asia. Findings suggest that much of Bangladesh (notably Dhaka), parts of southern and western Myanmar (the Ayeyarwady region and Rakhine state), and parts of southern and northwest Pakistan

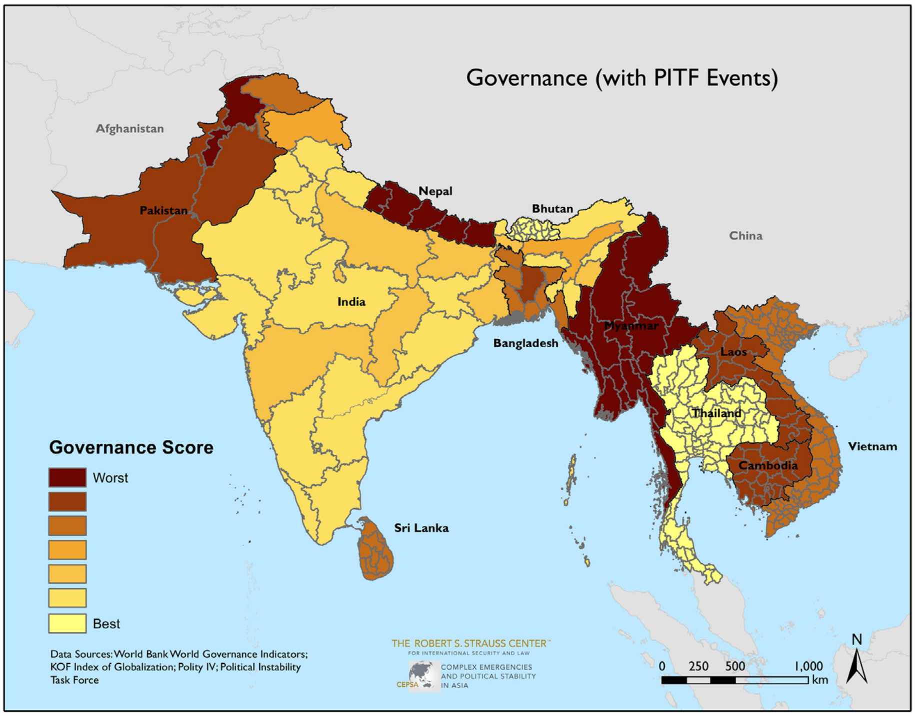


**Fig. 4.** Governance.

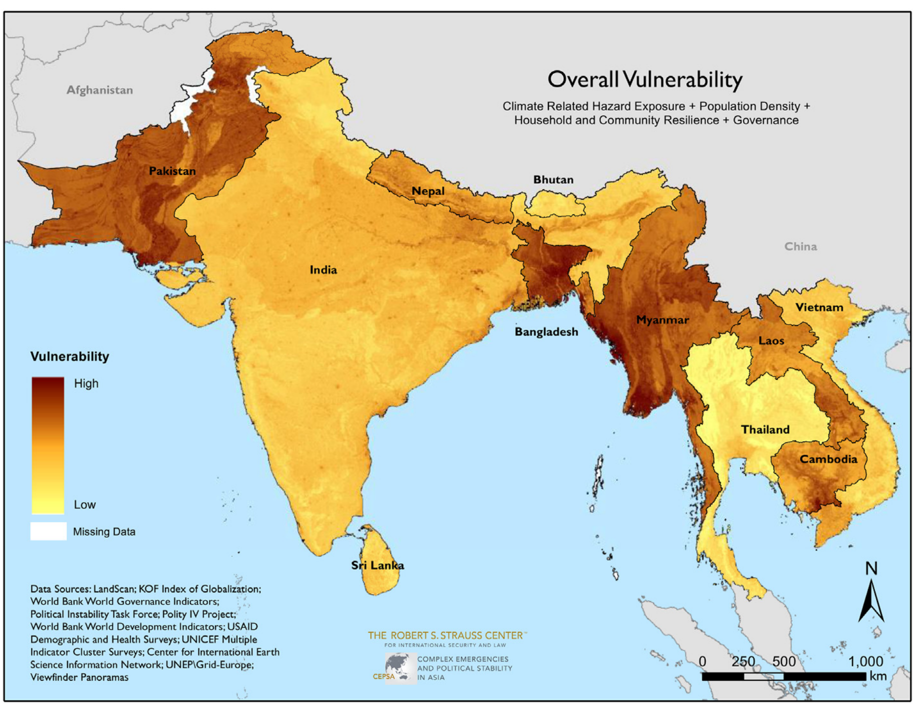


**Fig. 5.** Composite vulnerability.

(namely Sindh and Khyber Pakhtunkhwa provinces) are the most vulnerable locations from a climate security perspective (see Fig. 5 and Appendix Figs 22–24 for three Country Pullouts).[14]

Leaving aside the resilience and governance baskets, a slightly different perspective comes through when we simply evaluate the population exposed to climate hazards. Here, the largest numbers of people who are 1 or 2 standard deviations (SD) above the pixel mean for exposure are in India, followed by Bangladesh and Vietnam. In terms of the proportion of the total population in the country significantly above the pixel mean, Vietnam and

[14] Sindh province is site of the country's largest city Karachi with an estimated population of about 23 million.

**Table 1**
Estimates for population above pixel mean for exposure.

| Country | Total population | Population above mean exposure | Population above mean exposure | Population more than 1 SD above mean exposure | Population more than 1 SD above mean exposure | Population more than 2 SD above mean exposure | Population more than 2 SD above mean exposure |
|---|---|---|---|---|---|---|---|
| Bangladesh | 163,496,274 | 142,571,820 | 87.20 | 113,416,389 | 69.37 | 84,120,461 | 51.45 |
| Bhutan | 726,713 | 32,956 | 4.53 | 578 | 0.08 | – | 0.00 |
| Cambodia | 15,150,450 | 13,322,154 | 87.93 | 8,859,879 | 58.48 | 5,391,756 | 35.59 |
| India | 1,219,458,620 | 334,503,325 | 27.43 | 159,076,844 | 13.04 | 83,280,725 | 6.83 |
| Lao DPR | 6,671,234 | 1,769,244 | 26.52 | 231,034 | 3.46 | – | 0.00 |
| Myanmar | 54,821,916 | 22,271,833 | 40.63 | 10,155,477 | 18.52 | 5,707,483 | 10.41 |
| Nepal | 30,364,969 | 8,858,449 | 29.17 | 618,404 | 2.04 | 41,862 | 0.14 |
| Pakistan | 193,203,802 | 147,959,257 | 76.58 | 16,411,033 | 8.49 | 3,280,868 | 1.70 |
| Sri Lanka | 21,394,984 | 15,811,654 | 73.90 | 3,081,124 | 14.40 | 1,222,300 | 5.71 |
| Thailand | 67,401,048 | 47,168,014 | 69.98 | 23,632,032 | 35.06 | 15,788,112 | 23.42 |
| Vietnam | 92,234,358 | 66,384,431 | 71.97 | 48,570,945 | 52.66 | 40,986,383 | 44.44 |

Bangladesh stand out followed by Cambodia and Thailand (see Table 1).[15]

## 4. Validation with Germanwatch and the EM-DAT International Disaster Database

Do these maps reflect an underlying reality or are they merely the artifact of model assumptions? We try to validate this research by comparing our findings to those of other research projects that have carried out similar work using different methodologies. This too is challenging because comparisons can be misleading.

As we have previously discussed, climate vulnerability can be captured in a variety of ways, with different emphases on livelihoods, food security, and other indicators, depending on the interests and training of the research team. Methods include composite indices that aggregate indicators of vulnerability into a single metric as well as overlaying climate hazards on other indicators of concern such as political stability (Busby et al., 2014b, Busby et al., 2013). In previous work, we compared our model findings with other work such as the Verisk Maplecroft maps of subnational vulnerability (Verisk Maplecroft, 2017). However, these are proprietary products less subject to scrutiny by scholars, with indicators, data sources, and purposes related but not fully compatible with our research. Moreover, patterns observed in global vulnerability indices such as those by Verisk Maplecroft are not directly comparable to regional maps where pixels are normalized to show relative vulnerability within a specific region.

Despite these caveats, some studies by other research teams provide useful points of comparison. For example, Germanwatch produces an annual report assessing the relative risk of different countries to climate-related disasters. In their 2017 report, they evaluate the relative risk over the period 1996–2015. Their index, based on Munich Re climate-related disaster data, is a combination of total lives lost, lives lost per 100,000 population, disasters losses, and losses per unit of GDP. They find that a number of our focus countries are among the top ten in the world for climate risk including Myanmar (ranked number 2), Bangladesh (6), Pakistan (7), Vietnam (8), and Thailand (10). Other states in our study area included Cambodia (13), India (14), Nepal (24), Sri Lanka (54), Laos (87), and Bhutan (109). Several of these countries are featured among our most vulnerable including Myanmar, Bangladesh, and Pakistan while Thailand has low vulnerability in our model but is among the top ten in theirs. That could be a function of the emphasis in Germanwatch on economic damages, which in Thailand, as a middle-income country, are the main driver of its high climate risk score.

Another promising way to corroborate our findings is to compare our maps to the locations featured in the EM-DAT International Disaster Database (for a similar effort, see Naumann et al., 2014). EM-DAT is the most widely used database that records disaster situations that have risen to a certain level of damage.[16] The dataset records event particulars, including dates, locations, hazard type, casualties, numbers affected,[17] and total damages (if available). These estimates are derived from multiple sources, often Red Cross reports, and are triangulated across government and news sources and other reporting groups. Estimates likely have some errors based on reporting and challenges of adequate counting of the dead and population affected. Nonetheless, as a portrait of the relative magnitude of effects of different events, EM-DAT is the most reputable standard for which there is some open access.[18] That said, as Gall et al. discuss, all disaster indices have a number of limitations, EM-DAT among them. These include temporal and spatial reporting biases (the data get better over time and yet there may be some countries with better coverage than others), challenges of reporting damages related to droughts (partially a reflection of it being a slow onset disaster), and the lack of transparency over discrepant damage estimates and how those are reconciled (Gall, Borden, & Cutter, 2009). Nonetheless, EM-DAT is the most widely accessible and cited data source in this space, providing a portrait of the relative magnitude of effects of different events, and serves a useful purpose for comparisons.

In previous work on Africa, we geo-coded the database at the first administrative level, drawing on the geographic information recorded in EM-DAT (Busby et al., 2014b). EM-DAT typically lists the name of a city, province, or region for each disaster event, with events sometimes mentioning multiple provinces. A handful of cases fail to include geographic identifiers.[19] EM-DAT's coverage of climate-related disasters (and estimates of the number of the people killed and affected) is most closely related to our emphasis on threats to loss of life from exposure to climate hazards. We thus seek to see if the patterns of our composite map possess any parallels to

[15] These estimates are derived from spatially intersecting LandScan 2013 measures of population and our climate vulnerability index. We first estimate the mean climate vulnerability of our region and calculate the thresholds for 1 and 2 standard deviations above the mean. Then, using these thresholds, we use our population data to estimate the numbers of people (and their location) exposed at 1 and 2 standard deviations above the mean exposure.

[16] For a disaster to be entered into the database at least one of the following criteria must be fulfilled: ten (10) or more people reported killed, one hundred (100) or more people reported affected, a declaration of a state of emergency, or a call for international assistance (CRED, 2012).

[17] Affected numbers do not include estimates of the dead.

[18] Munich Re and Swiss Re insurance companies have proprietary data.

[19] EM-DAT events with no specific geographic data (other than country at large) amounted to 13 out of 2414 unique events (less than 0.1%).

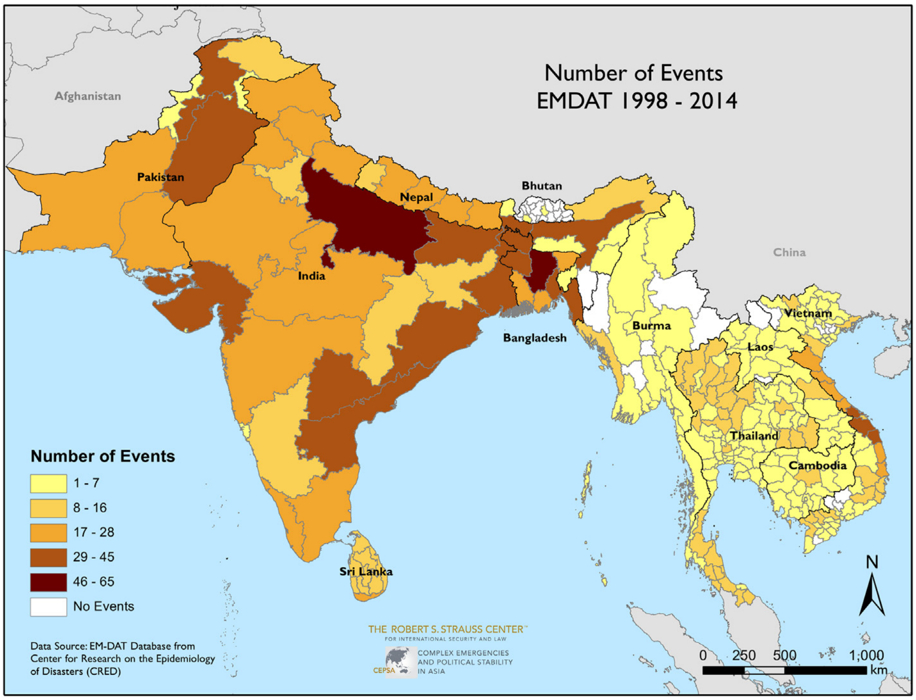


**Fig. 6.** Climate disaster events in the region.

the distribution of events, deaths, and people affected in the EM-DAT disaster database.

With the participation of AidData,[20] we geo-coded climate-related disaster event data for our eleven countries for the period 1998–2014, following a similar methodology. These data were coded to the first administrative level. Hazard types included droughts, floods, storms, wet landslides, wildfires, and extreme temperatures.

We map the number of events, the number killed, and affected by the first administrative unit. This poses a number of challenges. Because EM-DAT does not report casualty counts by specific geographic units, we have to apportion casualties where multiple administrative units are mentioned. Events often mention multiple provinces or subnational regions affected. These regions may be of unequal population size. Thus, if 100 people are killed in 4 administrative units, we initially apportioned 25 deaths to each in the first iteration. We did the same for the number of people affected.[21] We recognize that equally apportioning deaths/affected to administrative units is problematic, given that some have larger populations than others. We thus also apportioned numbers based on the respective administrative unit's population. While our data on deaths and affected come from various years, we based our scaling on LandScan estimates of population by administrative unit for a single year, 2013. We recognize that by using a singular measure for population density, we do not accurately account for population changes. However, with countries like Pakistan not having had a census since 1998, there are not reliable time series population estimates for some countries in the region. While this is a rough approximation, this offers an improvement over merely apportioning casualties equally across administrative units. Thus, if 100 people died in 3 provinces and the population distribution in state A was 100,000, states B and C were 50,000, we would distribute the losses as 50% to state A and 25% to each of the other states.

In addition, we scale aggregate losses in relation to the population size in the first administrative unit to take into account that first-level administrative units across the region are of varying sizes and populations. Thus, we take the weighted sum of deaths and the weighted sum of affected populations over the entire period and scale those totals in relation to LandScan 2013. To be able to represent the results on the same scale as our composite map for adequate comparison, we then normalize the scores across all geographic units on the same percent rank scale to show the standing of each first-level administrative unit relative to the rest of the region.

Figs. 6–8 show maps of the number of events and normalized versions of people killed and affected for the region relative to the population size in the administrative unit. Comparisons with our maps provide some areas of overlap. In terms of event numbers, central Bangladesh is common to our model and EM-DAT. In terms of fatalities, southern Myanmar shows up in Fig. 7 as well as our maps, largely attributable to Cyclone Nargis in 2008. In terms of population affected, Odisha in northeastern India shows up more strongly in EM-DAT maps as compared to our vulnerability map. Many of the small administrative units in Thailand, Cambodia, and Vietnam show up in these affected numbers. This may be a function of their small size and low population numbers so while large absolute numbers are not affected by disasters, relatively high proportions of the population are. If results are not scaled by population size in administrative divisions, India stands out even more prominently, mostly because of large population sizes in geographically large first-level administrative regions.

Pakistan, Bangladesh, and Myanmar, which feature most prominently in our composite maps, are not as disaster-prone in terms of high proportions of people affected according to EM-DAT. This may be a function in part because of reporting differences. Casualty counts and fatality statistics in EM-DAT are derived from multiple sources like the Red Cross.[22] Violent areas or repressive regimes

[20] See http://aiddata.org/.

[21] Results not shown. Contact the authors.

[22] See Appendix Table 5 for details on discrepancies in EM-DAT events.

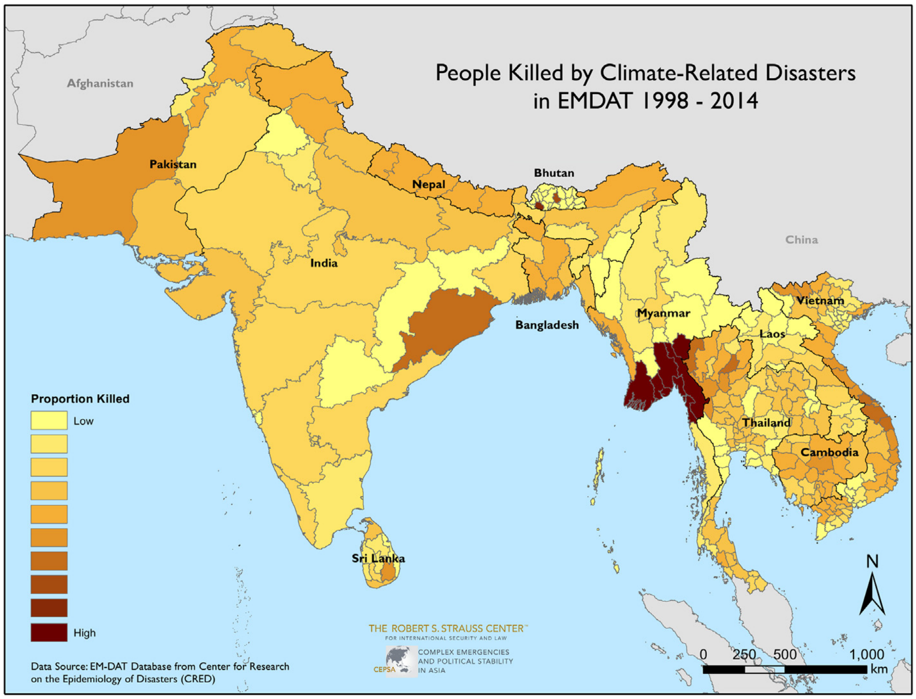


**Fig. 7.** Climate-related disaster deaths (proportional to population, population weighted).

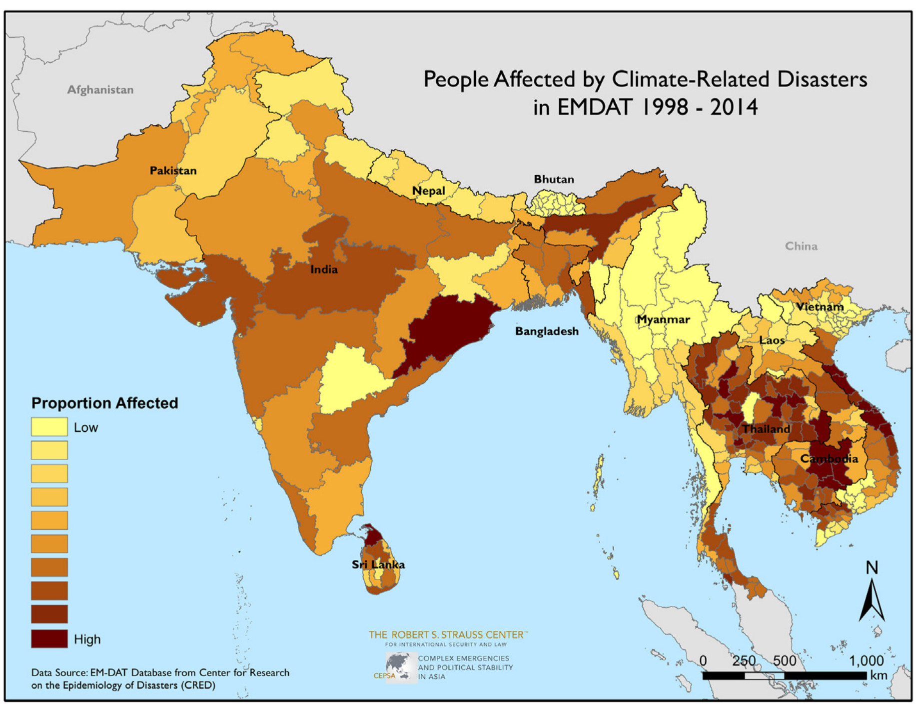


**Fig. 8.** Climate-related disaster affected (proportional to population, population weighted).

may not have free media or readily declare emergencies. Moreover, in those countries, intergovernmental and non-governmental organizations may not be able to perform reliable assessments, whereas democratic countries like India may have more vigorous civil society organizations than other countries. These sources provide important and necessary information for EM-DAT. Indeed, we face this limitation as the tribal areas in northwestern Pakistan and the disputed region of Kashmir lacked household data and thus are excluded from our composite index. Thus, whether EM-DAT patterns, our composite, or some other model reflects the true portrait of the underlying reality bears further scrutiny.

## 5. Alternative aggregation schemes and results from an expert survey

We also conduct sensitivity analysis of our model. In this section, we provide alternative functional forms of the model and change the basket weights based on an expert survey.

The findings of the composite map reflect the choices we made in terms of indicator selection and model aggregation. To lay bare the outcome of these choices, we first constructed four alternative composite indices, one with only two baskets (population and exposure), two with three of our baskets, and a fourth that places more weight on physical exposure. We also generated re-scaled sub-regional versions, one for South Asia and another for Southeast Asia.

One potential critique of our four-basket model is that it is too complex and adds little beyond what can be observed by a simplified two-basket model of physical exposure and population. If this were true, there would be little difference between the four-basket and two-basket model, but this is not what we observe. The two-basket composite of physical exposure and population brings out coastal locations in the pathway of cyclones around the Bay of Bengal and major cities such as Bangkok and Hanoi (see Appendix Fig. 1). The vulnerability in Myanmar and Pakistan, driven by household and governance indicators, largely recedes. This can be observed through the difference map where areas in blue reflect areas less vulnerable in the two-basket composite compared to the four-basket composite (see Appendix Fig. 2).

The three-basket composite, which adds household to physical exposure and population, brings in more of Pakistan's challenges (see Appendix Fig. 3). For India, low levels of household resilience in the northeastern states of Jharkhand and Bihar contribute to heightened vulnerability. Again, Myanmar's high vulnerability, due to governance, is not observed here (see Appendix Fig. 4 for the difference map).

As mentioned earlier, our model explicitly is biased towards large population centers based on the assumption that policymakers will care more if large numbers of people are at risk of death. We recognize that less densely populated areas may also face exposure to climate hazards. The patterns change in our vulnerability index by removing population and by constructing a three-basket index based on physical exposure, household resilience, and governance. Without population, much of Pakistan, Laos, and Myanmar, which are less densely populated, become more vulnerable while vulnerability in India and Thailand vulnerability is reduced (see Appendix Figs. 5 and 6).

The final alternative composite overweights physical exposure by multiplying it by the sum of the other three baskets, with each of the remaining baskets weighted equally. This ensures that a location with low physical exposure to climate hazards and high vulnerability on the other three dimensions could not be considered vulnerable to climate change. Here the patterns are largely similar to those in our final four-basket map, though perhaps a little less stark in Pakistan, Bangladesh, and Myanmar (see Appendix Fig. 7).

Readers might also be wary that the aggregation to the eleven country regional level obscures variation within sub-regions. We thus clipped and re-normalized the data within their respective sub-regions, comparing pixels within South Asia and Southeast Asia separately. The regional portrait in South Asia is similar to our original findings, with southern Pakistan and most of Bangladesh being the most vulnerable. The Southeast Asia maps also show similar results, with coastal Myanmar and Shan State in the northeast as particularly vulnerable (See Appendix Figs. 8 and 9).[23]

In addition to these alternative aggregation techniques for the composite index, we collected evaluations of our methodology from eighteen regional experts. This effort was inspired by a similar exercise by Brooks, Adger, and Kelly (2005) and Yusuf and Francisco (2009). The motivation was to see whether regional experts individually and collectively had different ideas about model weights and choices of indicators.

**Table 2**
Alternative weightings from expert surveys.

| Expert | Physical | Population | Household | Governance |
|---|---|---|---|---|
| 1 | 15 | 10 | 25 | 50 |
| 2 | 15 | 15 | 30 | 40 |
| 3 | 30 | 20 | 10 | 40 |
| 4 | 15 | 10 | 45 | 30 |
| 5 | 20 | 10 | 40 | 30 |
| 6 | 30 | 10 | 30 | 30 |
| 7 | 20 | 20 | 30 | 30 |
| 8 | 20 | 20 | 30 | 30 |
| 9 | 40 | 20 | 10 | 30 |
| 10 | 35 | 15 | 25 | 25 |
| 11 | 26 | 24 | 25 | 25 |
| 12 | 25 | 25 | 25 | 25 |
| 13 | 40 | 10 | 30 | 20 |
| 14 | 40 | 10 | 30 | 20 |
| 15 | 30 | 40 | 10 | 20 |
| 16 | 35 | 35 | 15 | 15 |
| 17 | 60 | 20 | 10 | 10 |
| 18 | 40 | 20 | 30 | 10 |
| **Average** | **29.8** | **18.6** | **25** | **26.7** |

The experts were chosen from lists of participants in climate and security forums from the region, the United States, and Europe. Fifteen respondents provided information on their core country of expertise. Seven identified India as their main expertise, another three identified Bangladesh, two for Vietnam, and one each for Cambodia, Laos, and Nepal. Respondents indicated secondary expertise in a number of the other countries. Fifteen provided details on their professional background. Seven self-identified as academics, three as researchers/independent consultants, three as private sector, and one for government official and NGO practitioner respectively. Suggested basket weights vary considerably between survey respondents (see Table 2), but the average converges towards equal weighting of each basket, with the physical and governance baskets receiving a bit more emphasis and population less (29.8% physical, 18.5%, population, 25% household, and 26.7% governance). Experts varied the most on their suggestions for physical exposure, followed by the household basket and the governance basket. Their suggestions for the population basket varied the least.[24] A map based on these averages produces results very similar to our main composite map (see Appendix Figs. 10 and 11).

In addition, we produced alternative composite maps and difference maps that compare results between the original composite and the alternatives suggested by experts. Experts 1, 3, 4, 15, and 17 departed the most from our equal weighting scheme. Expert 1 overweights governance. Expert 3 underweights household resilience (elevating governance) while expert 4 overweights household (and underemphasizing physical and population). Expert 15 places more weight on physical and population. Expert 17 placed disproportionate weight on the physical basket, downplaying household and governance.

Overweighting governance (Expert 1) brings out Myanmar even more. Underweighting the household basket (Expert 3) has almost no impact on the maps. Overweighting the household basket brings out vulnerability in Pakistan, Myanmar, and Laos (Expert 4). Overweighting the physical and population baskets diminishes

[23] Contact the authors for results.

[24] Standard deviation for physical exposure 11.8, population 8.7, household 10.3, governance 10.3.

the vulnerability in Pakistan and Myanmar (Expert 15). Heavily overweighting physical exposure has an even more pronounced effect on Pakistan, Myanmar, and Laos, localizing the vulnerability to densely population cites along the coasts and rivers in Pakistan, India, Bangladesh, Myanmar, Thailand, Cambodia, and Vietnam (Expert 17) (for examples of these alternative composites and difference maps, see Appendix Figs. 12–21).

The question then becomes which of these specifications is a more accurate model of the real world. This portrait of vulnerability is useful so long as it captures as underlying reality. Vulnerability studies and hot spot mapping often suffer from the problem of a profusion of too many maps, potentially leads to information overload and knowing which maps best capture the underlying reality (de Sherbinin, 2014). As noted before, the model does not have an econometric basis. Such an effort would in any case be extremely challenging and not likely to provide us guidance, given the different kinds of climate hazards, spatial resolutions and time coverage of the underlying indicators.

Our initial conclusion is to assert the importance of politics and governance and retain the equal weights approach. While the governance metrics in our current iteration are relatively crude aggregations at the national level, such metrics are an important reminder that whether governments are willing and able to respond to emergencies is hugely important to whether thousands live or die. That said, such indicators, which largely rely on national measures, cannot capture other important sub-national dynamics.

A snapshot approach inevitably captures a moment in time, though these maps could be updated periodically to reflect more contemporary circumstances. To be sure, governance is dynamic in the region. For example, Myanmar is changing dramatically as it struggles to overcome its authoritarian past and the emergence of religious cleavages. Though the country faces similar physical exposure to neighboring countries in the Bay of Bengal, the 2008 cyclone was the deadliest in the region in recent times, a function of an insular regime that cared little about the lives of its citizens. A decade later, with a troubled transition towards more democratic rule, it is debatable whether a storm like Nargis would still kill such large numbers in Myanmar.

India, Pakistan, and Bangladesh face many of the same challenges associated with cyclones, coastal vulnerability, and flooding, yet these hazards have provoked major dislocation and loss of life in Pakistan while India has demonstrated improved capacity over time. The deadliness and scale of the 2010 floods in Pakistan have been attributed in part to a failed decentralization scheme, though there are reasons to believe that it had not yet been implemented at the time of the floods (Karamat, 2010; Flores & Smith, 2011; White, 2011).

The portrait of governance and disaster preparedness in Bangladesh is also an interesting story. An intense category 5 cyclone in 1991 killed more than 100,000, and Sidr, a cyclone of comparable magnitude in 2007, resulted in 15,000 deaths. That optimistic portrait of improved disaster preparedness in 2017 was being challenged by a state riven by more incidents of extremist political violence. Whether climate change has contributed to any of the contemporary security challenges of the Bangladeshi state deserves more explanation. In a 2011 edited volume, Ali Riaz wrote that climate change in Bangladesh threatened to accentuate migratory pressure to major cities, weaken the state's ability to deliver services, and strengthen authoritarian tendencies if sectarian violence could not be contained. He pointed out that servicing humanitarian needs has increasingly become the preserve of NGOs, both secular and Islamist, delegitimizing the state as guarantor of services. Climate change seems to be accentuating that trend. If nothing else, our maps underscore the need for more detailed case study work (Riaz, 2011).

The surveyed experts also provided some validation of our approach and results, largely agreeing that the patterns found reflected their understanding of the situation at hand. At least one expert was concerned about the relative lack of differentiation of vulnerability within India, and cited again the need for more nuanced understandings of within-country governance capabilities. Several suggested additional indicators that could capture other important processes. For household and community resilience, as one expert put it, there "needs to be some way of capturing the existence (or not) of social capital, the sense of 'connectedness' that the population experiences." At least two other experts echoed this view. Additionally, on the physical exposure side, experts advised the inclusion (or at least consideration) of heat waves and temperature changes. The next section outlines some of the steps we are taking to address some of these suggestions.

## 6. Next steps

This is the first iteration of the vulnerability index for Asia (ACSV V1). We intend to further refine the methodology based on the expert surveys as well as ground-truthing of the model. We carried out in person semi-structured interviews to validate our findings with regional experts. One of us traveled to India in December 2015, another to Bangladesh in May and November 2016 and Nepal in November 2016.

As noted, our survey of regional experts has already generated suggestions for extensions. For example, in light of the heat waves in summer 2015 that claimed thousands of lives in Pakistan and India, several experts recommended including heat waves in the model. Heat indicators have been found to be especially strong correlates of conflict incidence in a number of econometric papers on climate and security (Hsiang, Burke, & Miguel, 2013; Burke, Miguel, Satyanath, Dykema, & Lobell, 2009; Hsiang & Meng, 2014). Though such findings still beg some explanation of causal mechanisms of influence beyond heat wave-related mortality, heat waves are an important phenomenon that will be incorporated in the next revision.

In addition, land degradation likely makes the effects of extreme weather events worse. For example, Chennai, a relatively wealthy coastal city in southeastern India, in late 2015 endured devastating floods that left much of the city underwater and some 280 people dead. As many commentators noted, this was a man-made disaster as the city (and cities throughout the region) have experienced significant conversion of mangroves to urban infrastructure. Much urban development, including universities, roads, housing complexes and airports, across the region is being built on flood plains without sufficient regard for drainage and hazard exposure. Peri-urban areas with slum development are also often constructed on marginal areas subject to coastal inundation, flooding, and erosion (Jayaraman, 2015; Pereira, 2015; Sengupta, 2015). Therefore, we believe a measure of land degradation would be important to overlay on our physical exposure basket to capture the joint risk of climate hazards and land degradation. We are partnering with geographers from the University of Oklahoma to apply a new disturbance index (DI) to the region based on remote sensing data. The disturbance index can show changes in land cover in both rural and urban areas, reflecting deforestation as

well as conversion from agriculture to buildings and impervious surfaces.[25]

Another potential research area is further subnational disaggregation of the household basket. USAID DHS surveys have started to interpolate household indicators at the second administrative level through an approach called Modeled Surfaces. Heretofore, point estimates were only deemed sufficiently robust at the first administrative level. The Modeled Surfaces data is only available for 16 countries, mostly in Africa, and for a subset of indicators, though extensions are in progress.[26] The approach is likely replicable, but the code has not been publicly released, making replication a multi-year project. Even if further disaggregation is possible, vulnerability maps still likely mask variation in vulnerability within locations and even at the household level.

Another area of interest is how to capture subnational variation for countries such as India that had relatively undifferentiated vulnerability in our regional model. India, despite high population density and pockets of physical exposure, appears to be among the least vulnerable in the region with relatively undifferentiated vulnerability internally. Our national level governance indicators drive these undifferentiated patterns. As some of our experts suggested, this may be misleading, as India possesses considerable variation in state-level governance quality.[27] Though subnational metrics of government effectiveness are not readily available, India has better data than other countries in the region.[28] To capture internal variation within India, the team is developing sub-national governance metrics to create a country specific map that assesses Indian states relative to each other.

Beyond these considerations of localizing our maps still further and checking their fidelity with local experts' understandings, there is also a need to think beyond the nation-state to the implications of these findings for cross-border collaboration on shared resources. What does Bangladesh's widespread vulnerability mean for India and additional regional out-migration?[29] While some have offered over-wrought predictions of water wars, the reality has been one of water-sharing agreements including in key watersheds in this region such as the Ganges, Indus, and Mekong. However, many of these are increasingly under strain due to drought and unilateral dam-building projects (Ghazi, Muniruzzaman, & Singh, 2016). The history of conflict between neighbors, nationalism, and sovereignty concerns looms large and may make continued cooperation over resources a challenge. These transborder issues loom larger in light of the dislocation in 2017 of a half a million Rohingya refugees from Myanmar to Bangladesh, where many of them reside in areas that may be subject to monsoon rains (Loy, 2018).

## 7. Conclusion

Model results like this could potentially inform both local actors' decisions and in particular, external actors' policy interventions and priorities. Foreign actors have more extensive geographic interests than specific countries and generally have less comprehensive understandings of local challenges that may be intuitive to local and national-level actors. As a consequence, maps like these could usefully serve as heuristics for donors to guide further investigation of underlying mechanisms and attention.

That said, these maps are seductive and appealing in their simplicity, but do they depict an underlying reality? Already, there is a sort of reverse beauty contest set in motion by climate change in which countries are auditioning for resources by seeking to portray themselves to be the most vulnerable (Friedman, 2010; de Sherbinin, 2014). This exercise of resource allocation is potentially fraught, and maps like ours could be used for problematic purposes if deployed uncritically. As Klein argues, since there is no objective definition of vulnerability and different approaches may yield different results, the identification of most vulnerable places is ultimately subject to some political processes (Klein, 2009; Klein & Möhner, 2011).

Our maps, and particularly our validation efforts, nonetheless provide some intuition of underlying realities and are useful as a point of departure for deliberation and additional study. Our climate vulnerability maps are meant to serve as preliminary focal points for discussion and research with country and regional experts. By putting some maps on the table, we anticipate they will inspire a reaction and critical conversation. However, if policymakers blithely embrace these maps as guides for investment decisions, that itself would be a disservice. For one, our model necessarily privileges densely populated areas in a sort of utilitarian calculus of risks to large-scale loss of life. Do the lives of people in physically exposed areas matter less if there are fewer of them? Decision-makers need to be aware and critical of the assumptions of any model meant to inform their choices.

Our emphasis is on the risks of large-scale loss of life. While this is most obvious for swift onset events such as cyclones, flooding, and storm surge, mortality risk (and conflict) from slow onset disasters such as droughts are mediated more by the effects on food production and distribution, livelihoods, and government responses. Here, as Markey emphasizes in his account of climate change and security in Pakistan, climate effects could lead to security outcomes through indirect pressures and the opportunity costs they impose on states with limited resources, already facing other internal and external security challenges (Markey, 2015).

As academics and practitioners try to identify and understand priority places of concern, we believe this approach to hot spot mapping provides an integral foundation for further investigation. Time will tell if the maps and the exercise are useful.

## Conflicts of interest

None of the authors have any conflicts of interest.

## Acknowledgements

The authors thank the editors and the external reviewers for their helpful advice. The authors also thank the eighteen regional experts who reviewed the model for their feedback as well as experts consulted in Bangladesh, India, and Nepal during groundtruthing visits to those countries. The team also benefited from feedback from Emily Meierding who served as discussant for a panel at the 2016 American Political Science Association conference meeting where a draft of this article was presented.

[25] While an existing measure, the Normalized Vegetation Difference Index (NVDI), already incorporates greenness, the disturbance index is potentially better able to capture urban infrastructure through the incorporation of the other dimensions. (de Beurs, Owsley, & Julian, 2016).

[26] See http://spatialdata.dhsprogram.com/modeled-surfaces/.

[27] For one assessment of the security implications of climate change for India, see (Paul, 2011).

[28] For examples of a subnational Indian state level climate vulnerability mapping approach, see (Brenkert & Malone, 2005; Manupriya, 2016).

[29] India already has some 20 million Bangladeshis in the country and has invested in a border wall to deter future migration. For discussion of climate signals and previous conflict over Bangladeshi migration to India, particularly in Assam see (Bhattacharyya & Werz, 2015, 2012; Paul, 2011).

## Appendix

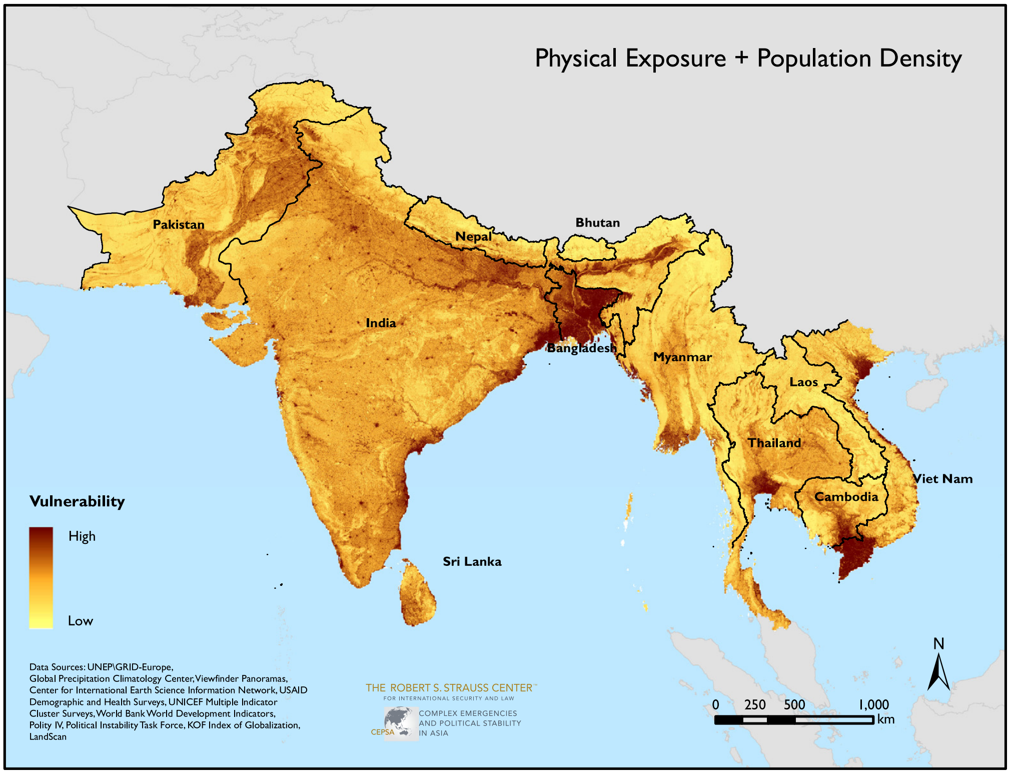


**Fig. A1.** Composite vulnerability – physical and population only.

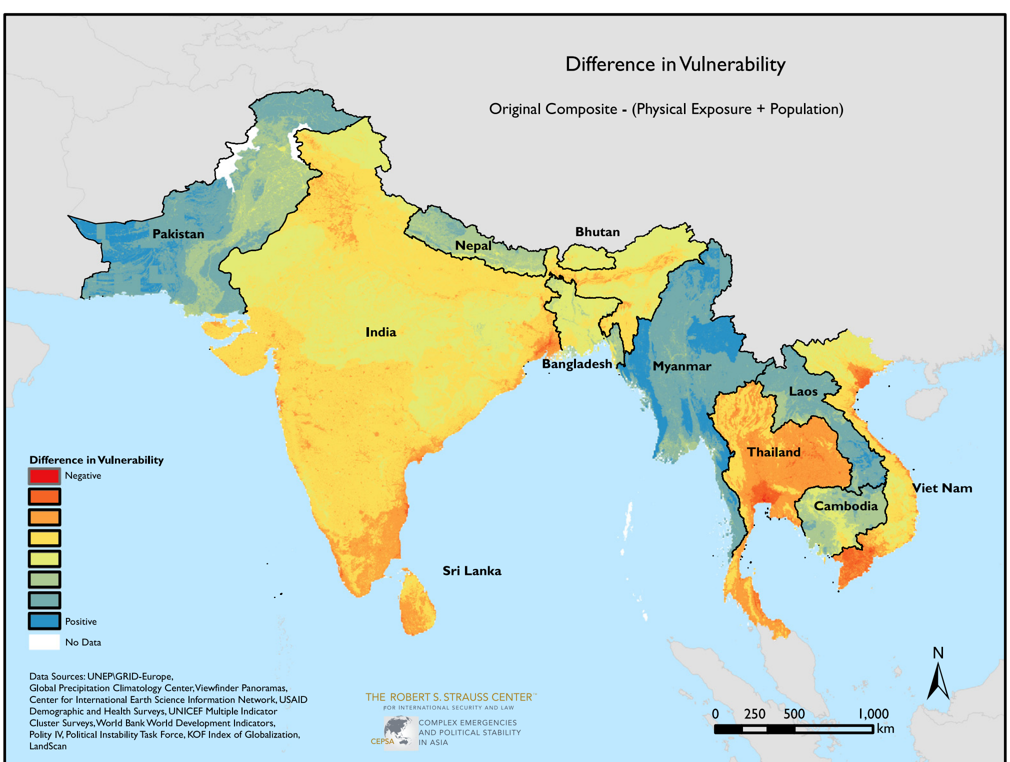


**Fig. A2.** Difference map between four and two-basket composite.

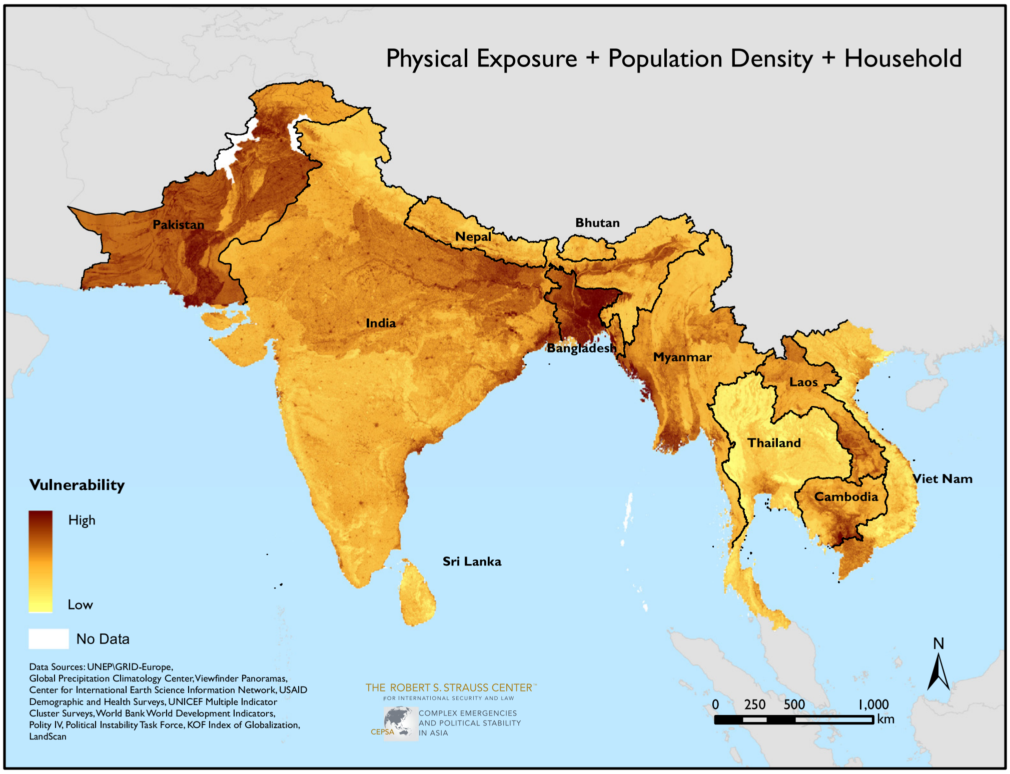


**Fig. A3.** Composite vulnerability – physical, population, and household only.

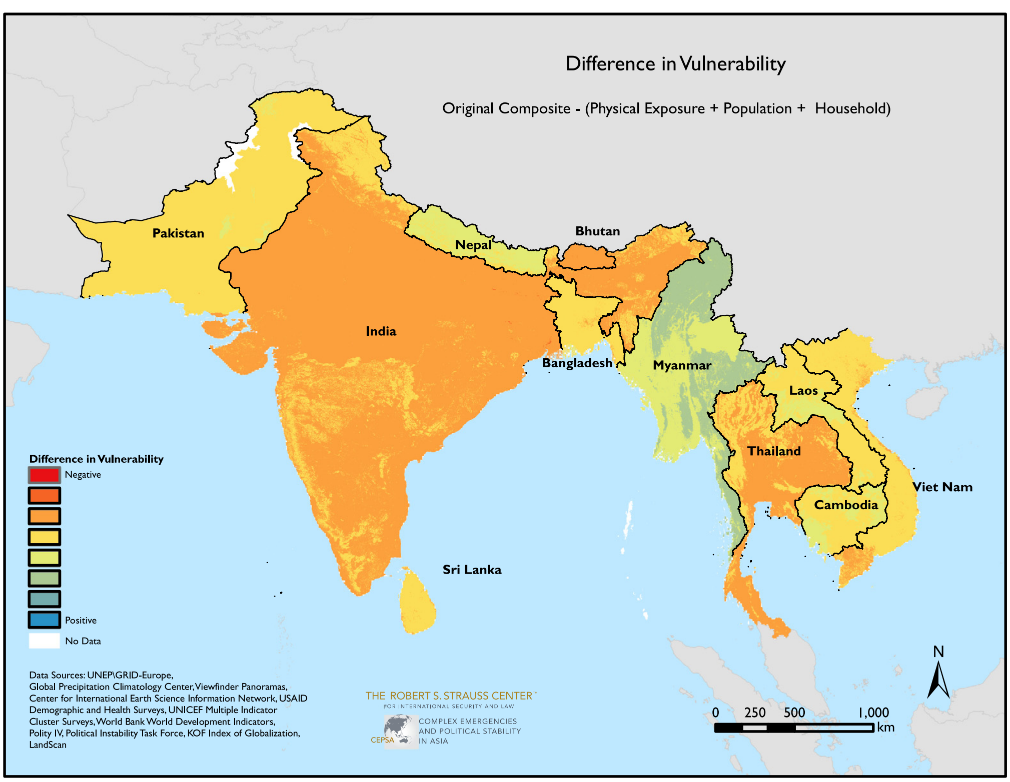


**Fig. A4.** Difference map between four and three-basket composite (physical, population, household).

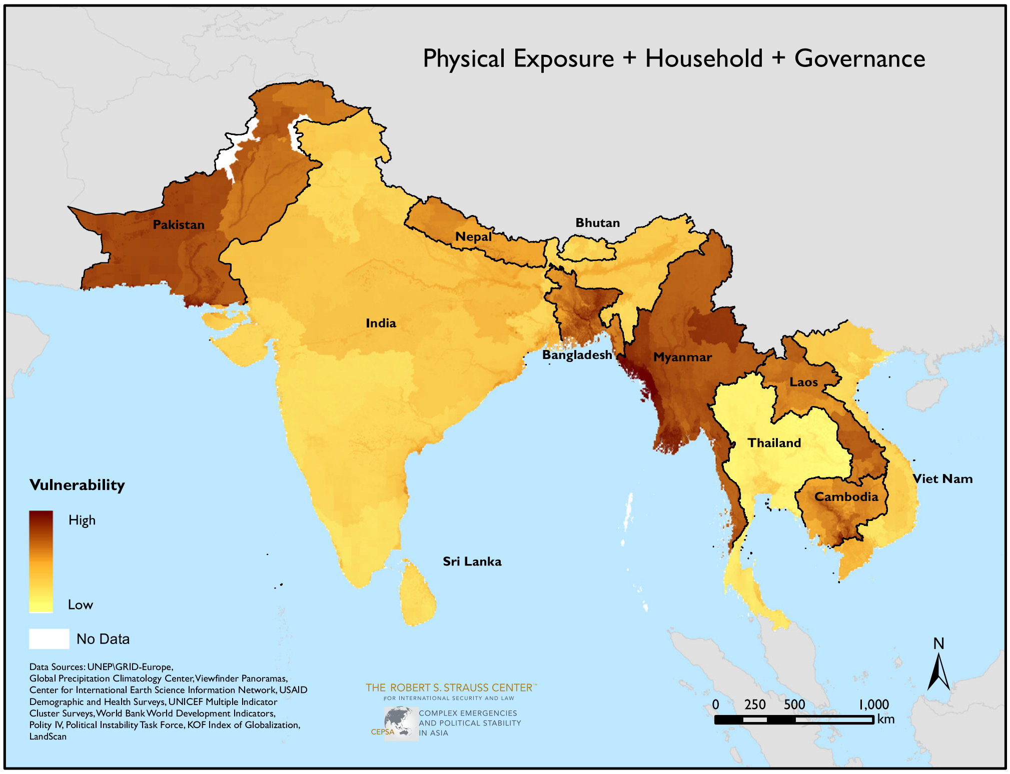


**Fig. A5.** Composite vulnerability – physical, household, and governance only.

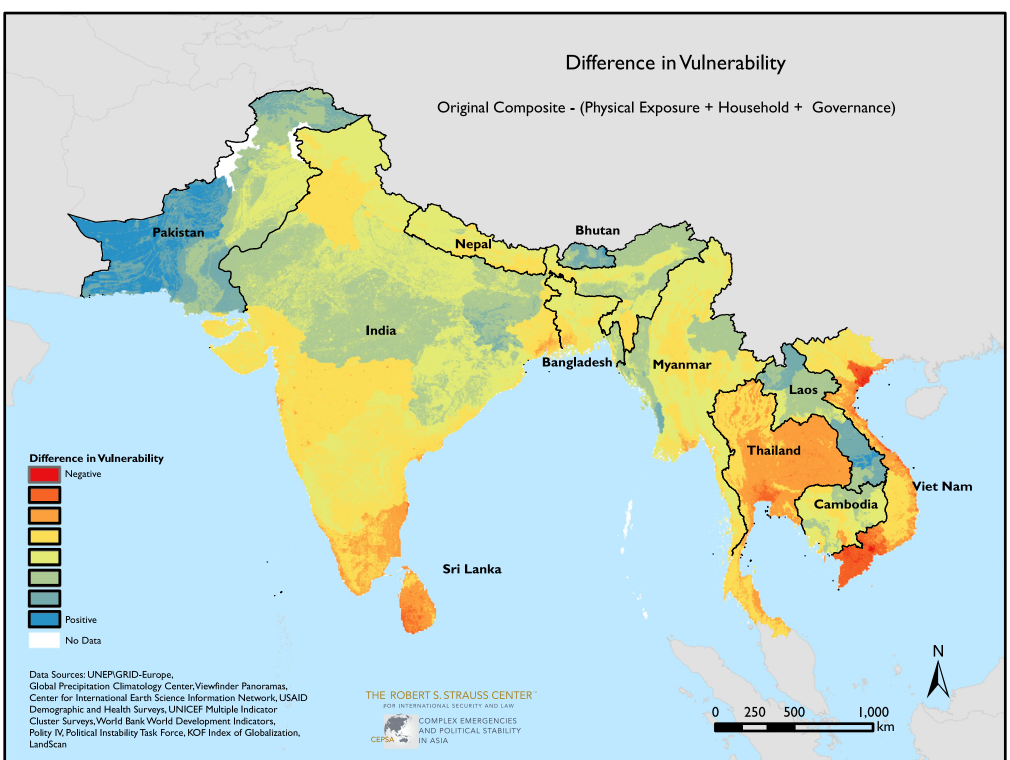


**Fig. A6.** Difference map between four and three-basket composite (physical, household, governance).

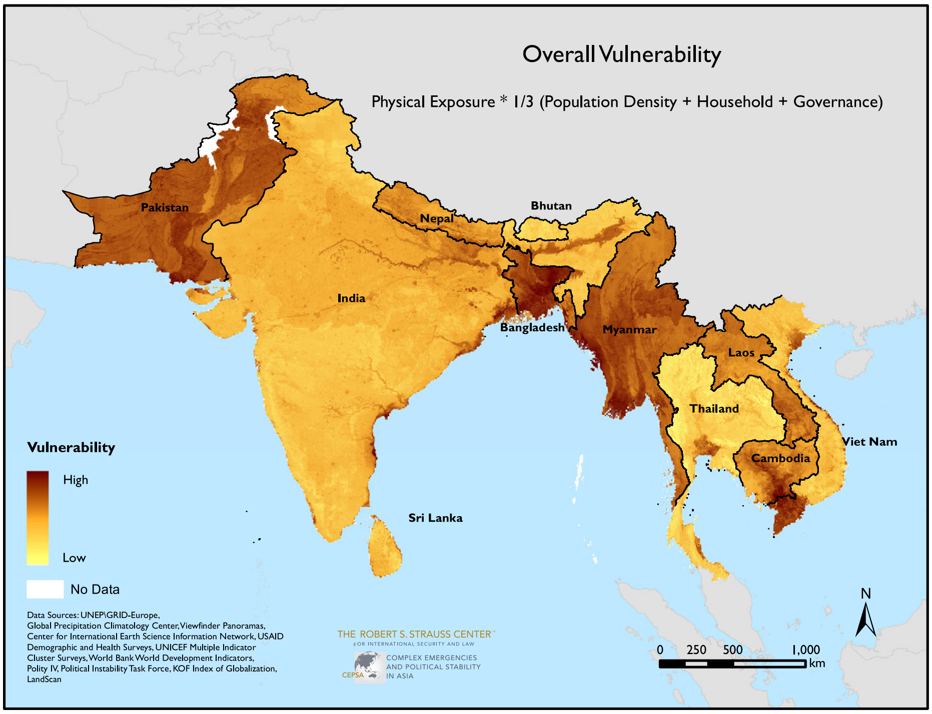


**Fig. A7.** Composite vulnerability – multiplicative index.

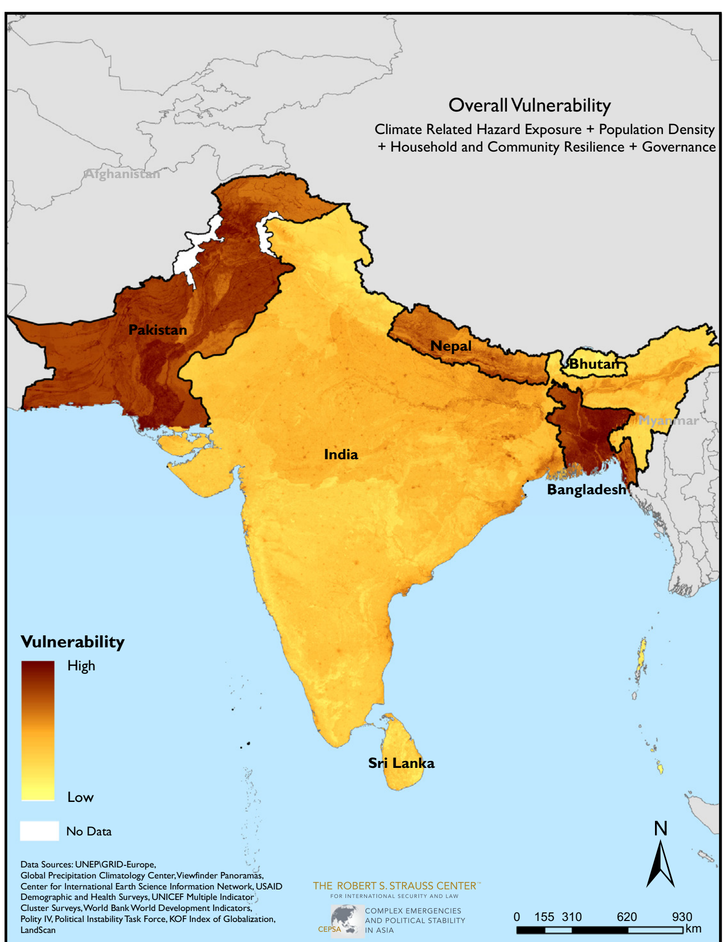


**Fig. A8.** South Asia only.

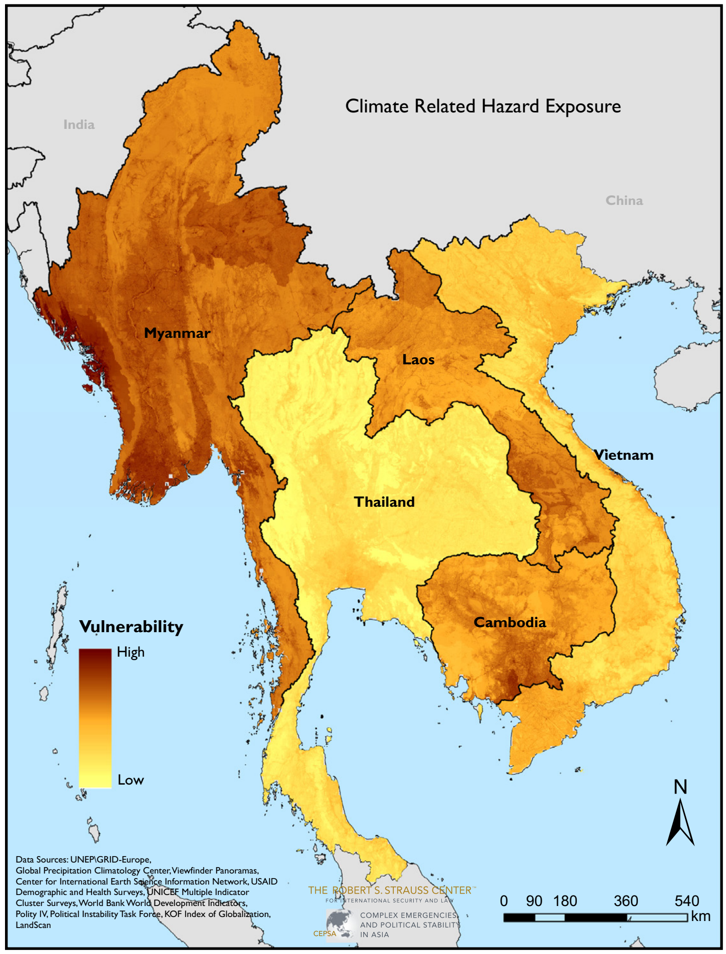


**Fig. A9.** Southeast Asia only.

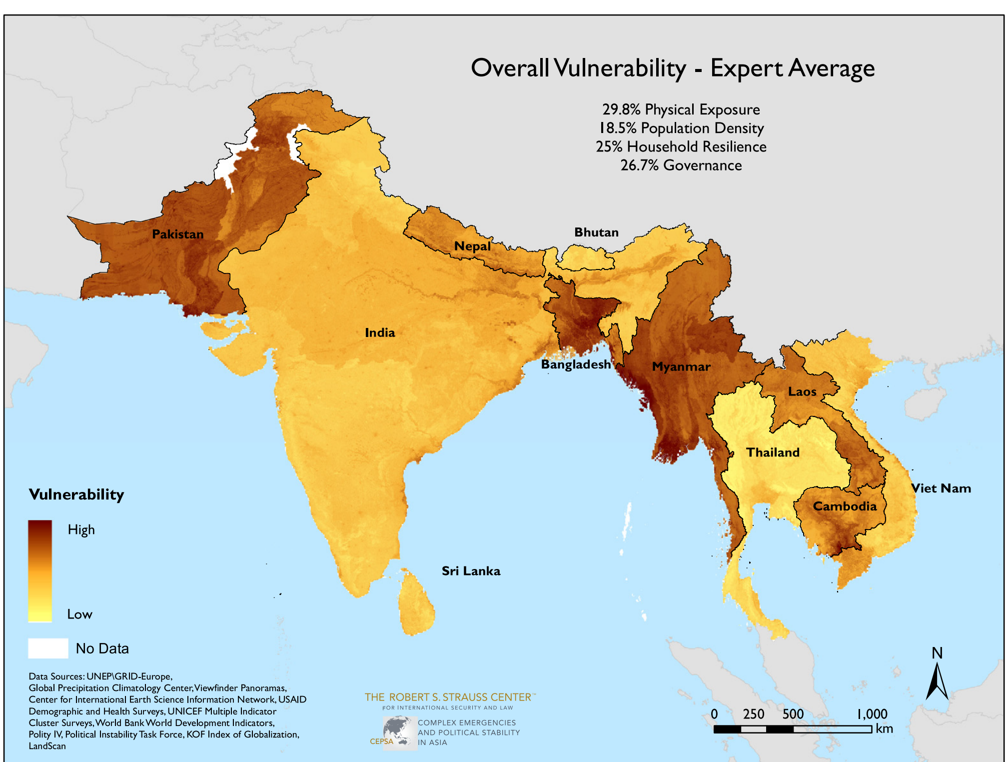


**Fig. A10.** Expert average.

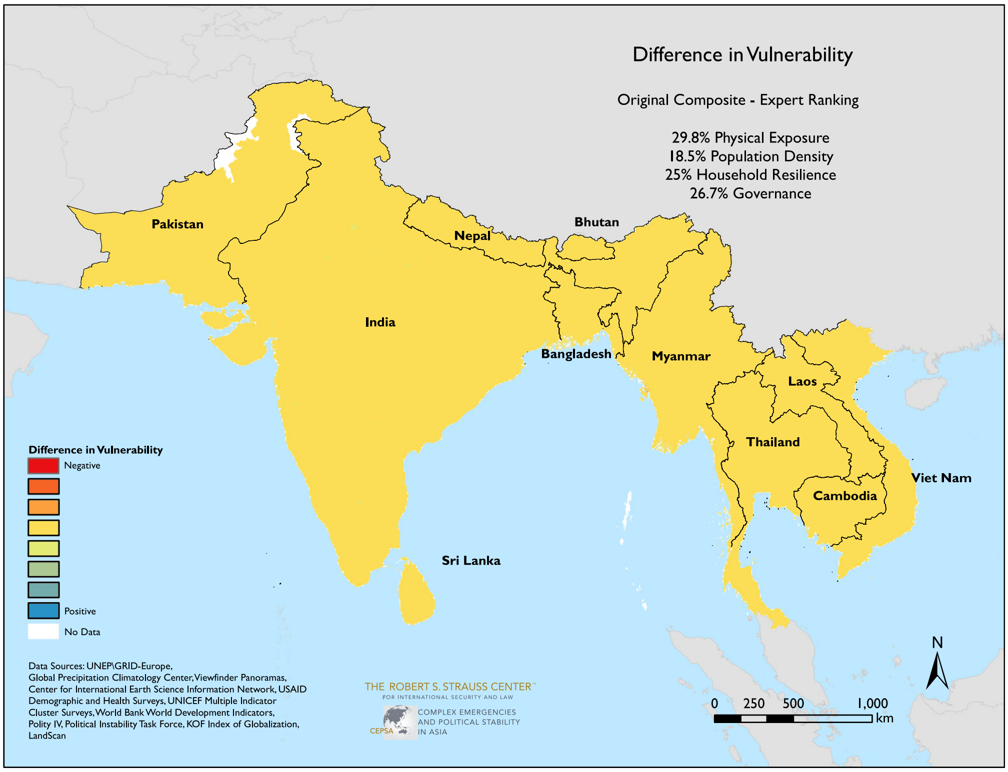


**Fig. A11.** Difference map between four-basket composite and expert average.

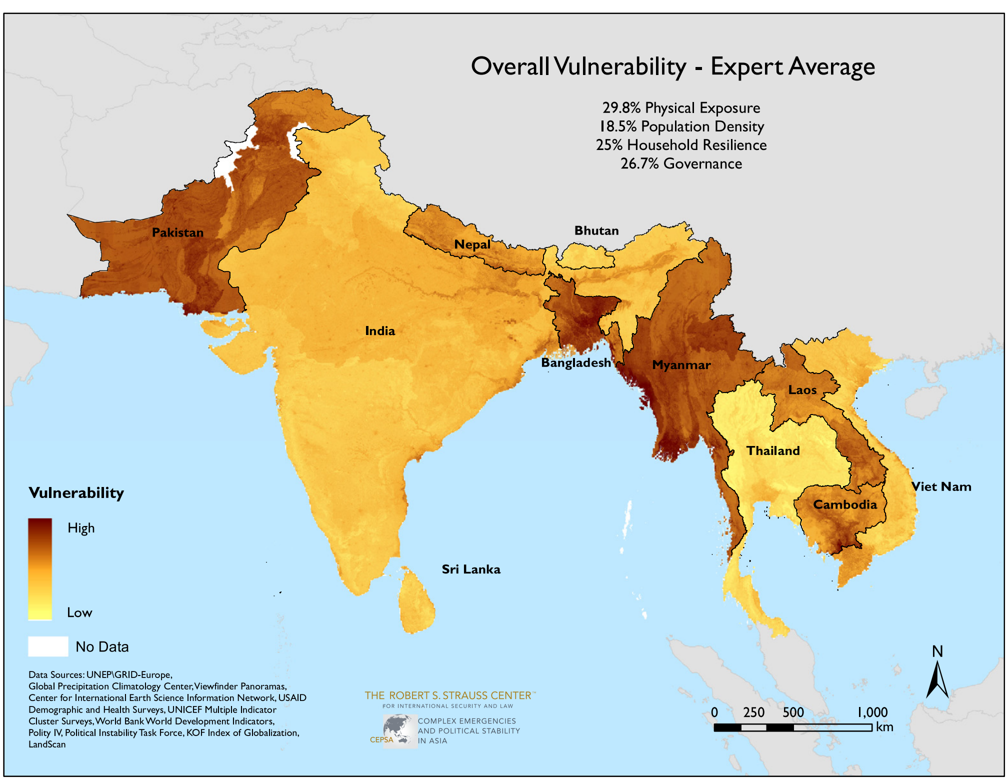


**Fig. A12.** Expert 1 map (overweights governance).

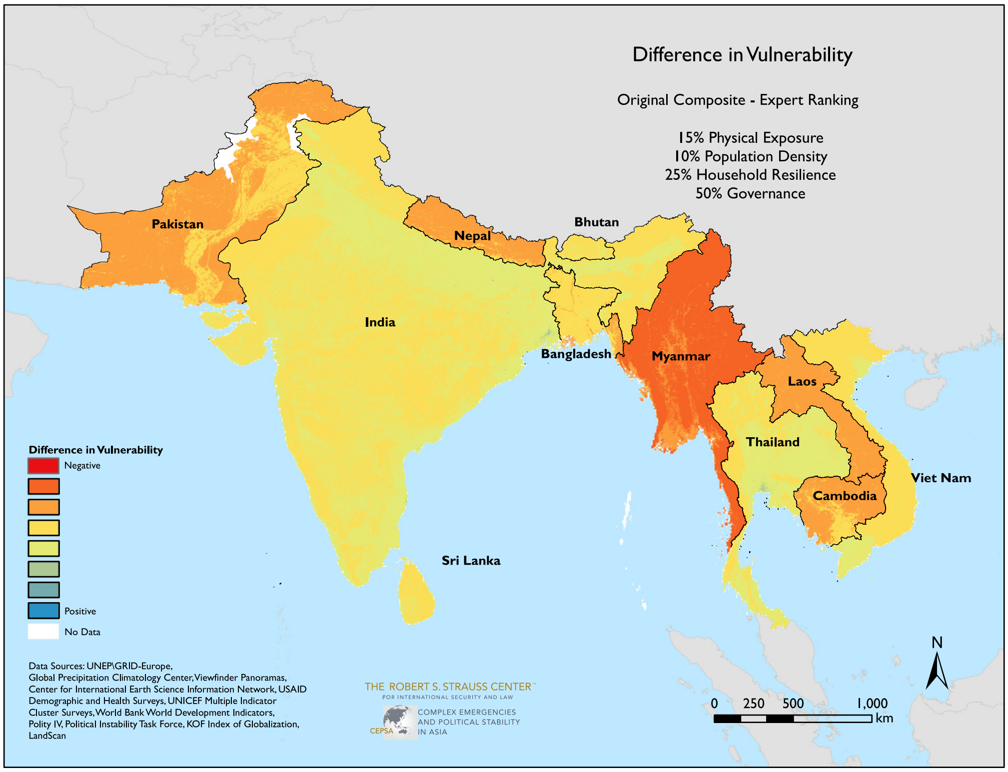


Fig. A13. Difference map between four-basket composite and expert 1.

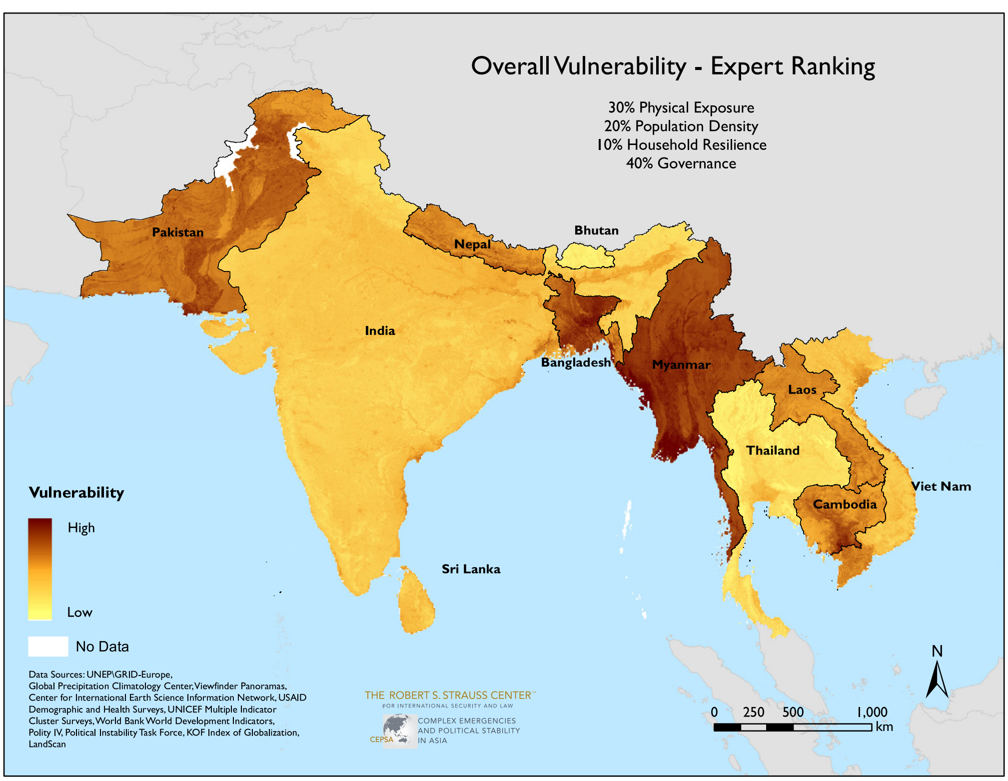


Fig. A14. Expert 3 map (overweights governance).

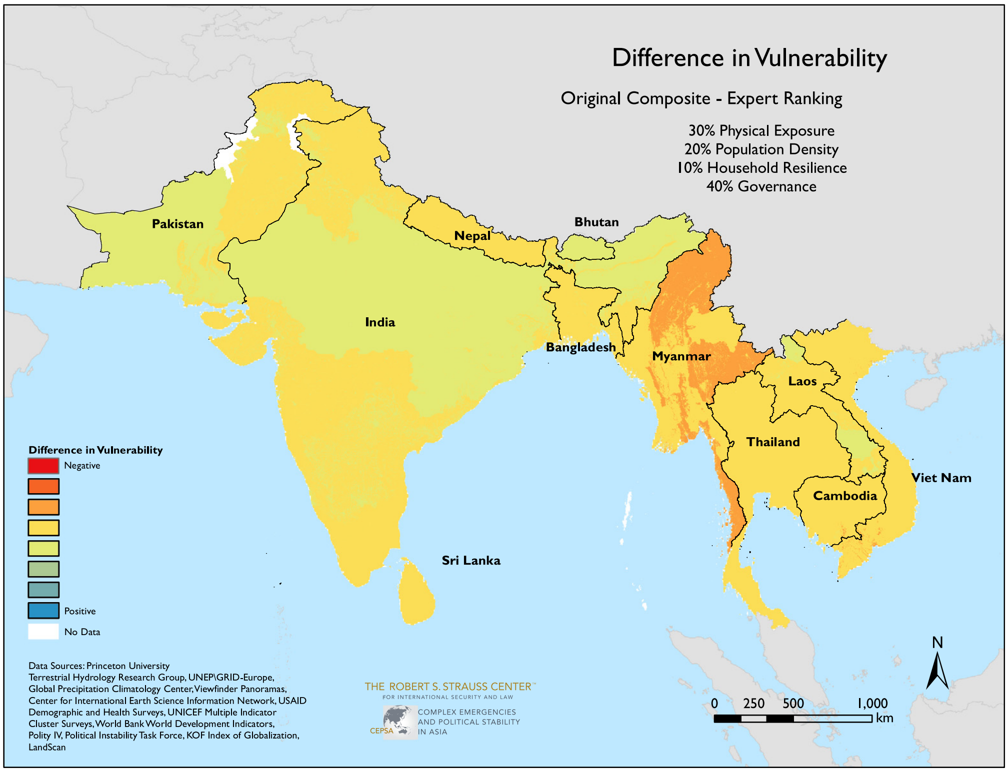


**Fig. A15.** Difference map between four-basket composite and expert 3.

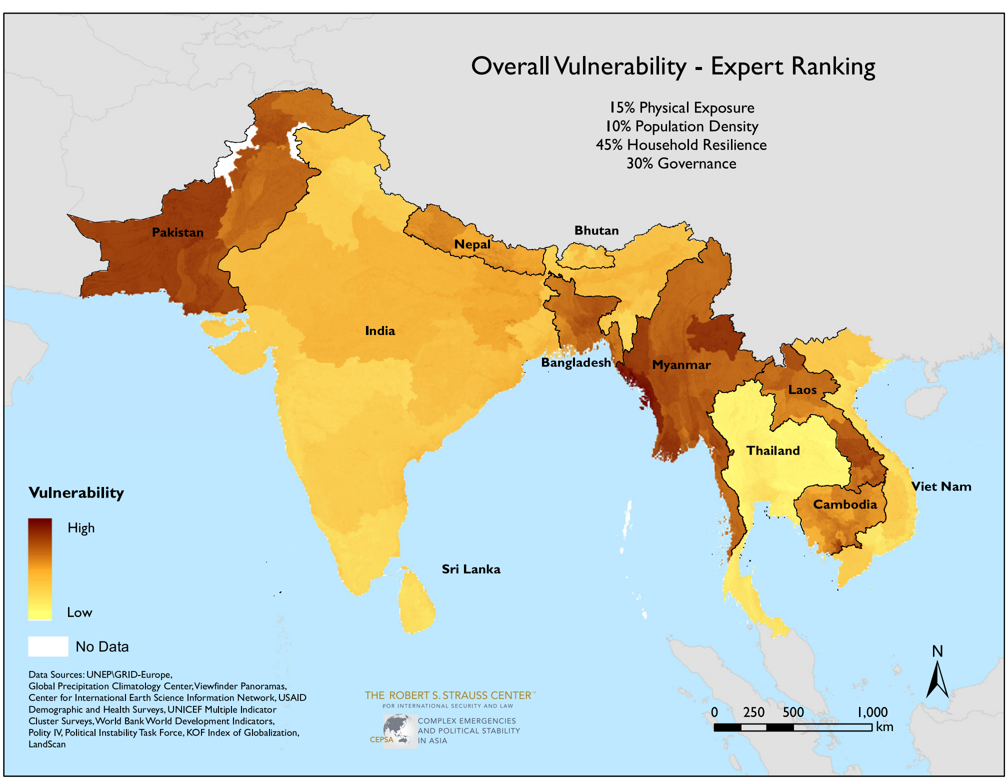


**Fig. A16.** Expert 4 map (overweights household).

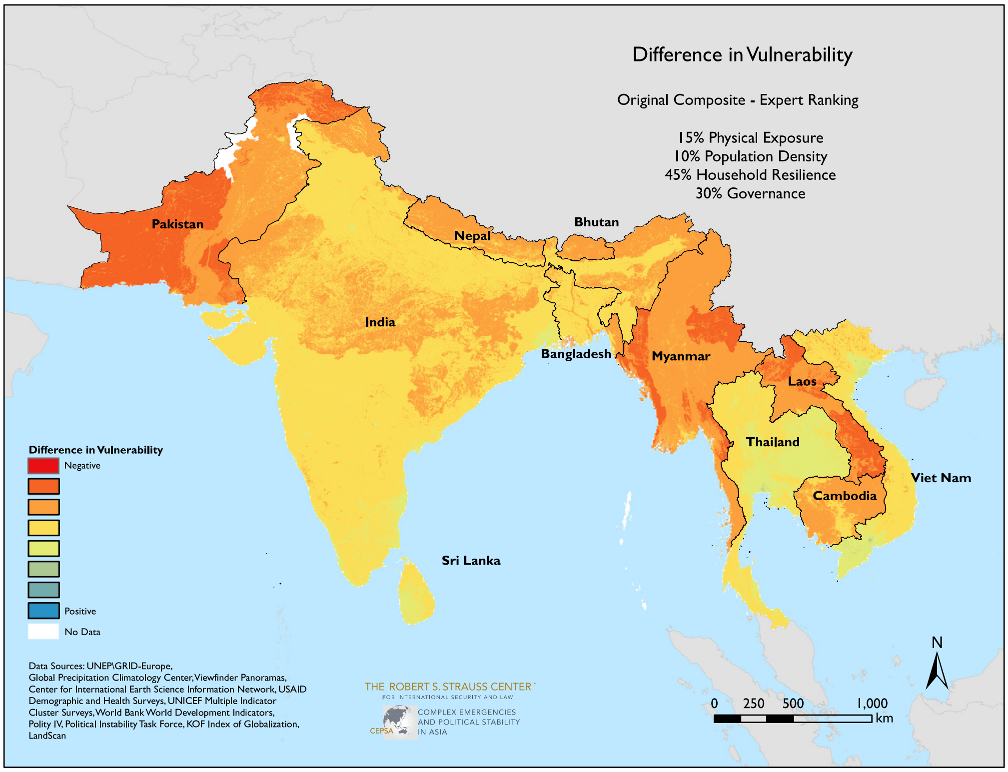


**Fig. A17.** Difference map between four-basket composite and expert 4.

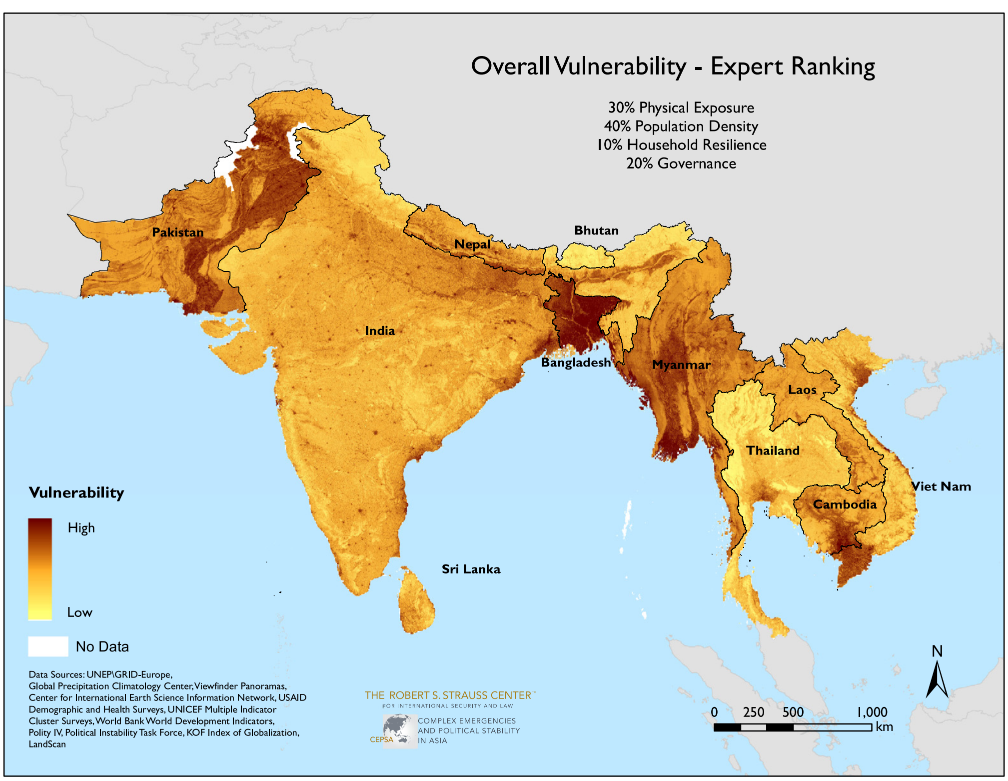


**Fig. A18.** Expert 15 map (overweights physical and population).

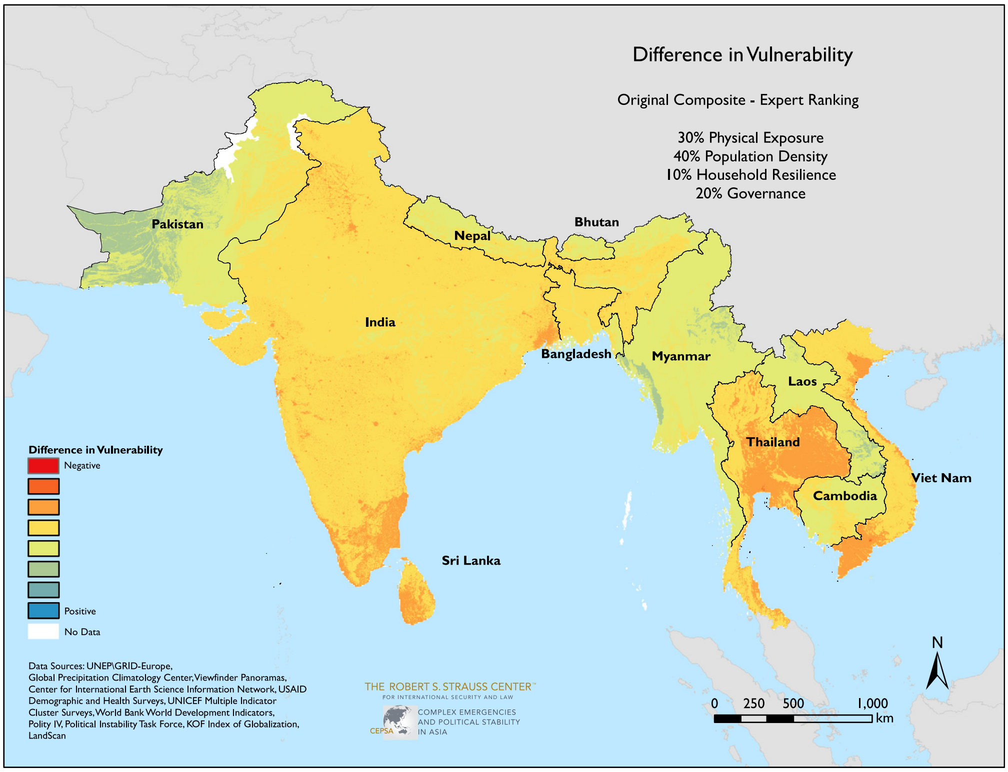


**Fig. A19.** Difference map between four-basket composite and expert 15.

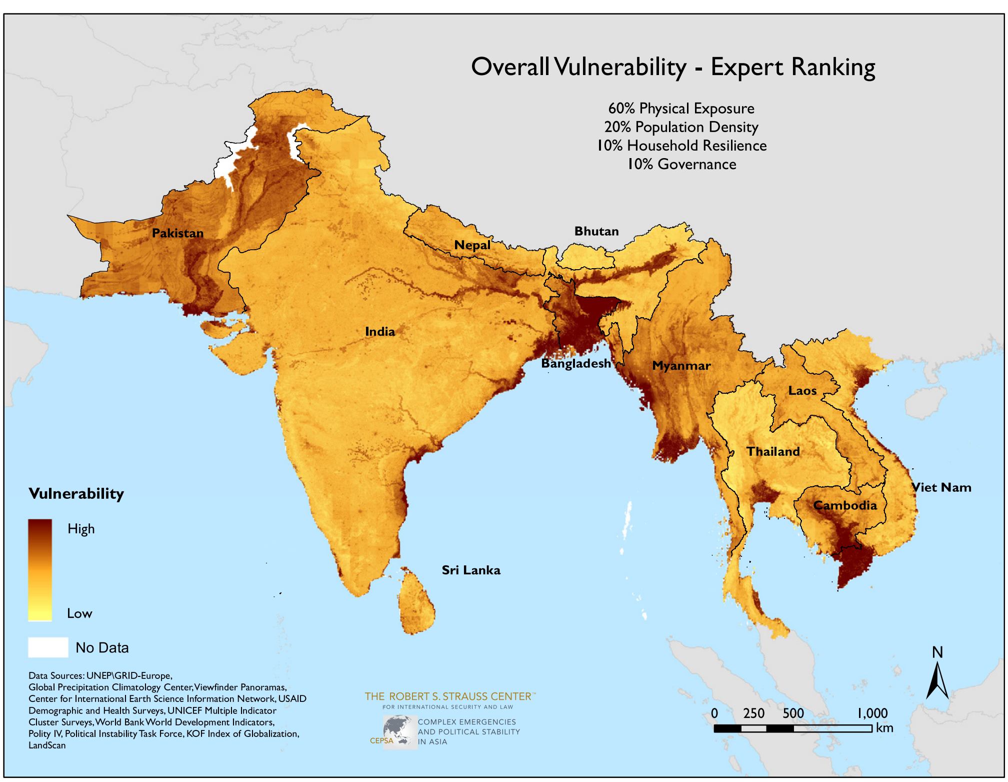


**Fig. A20.** Expert 17 map (overweights physical).

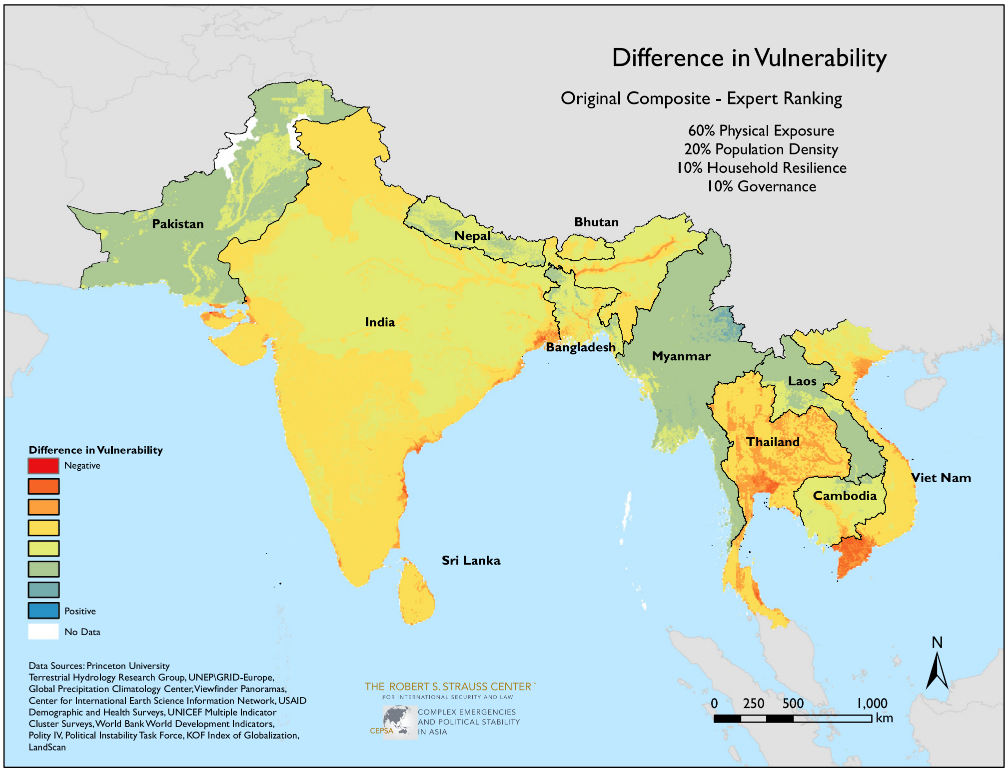


**Fig. A21.** Difference map between four-basket composite and expert 17.

Appendix Figs. 22–24 – Pullout Maps of Bangladesh, Myanmar, and Pakistan. These figures represent zoomed in versions of each basket layer and composite vulnerability in the central panel. The values are not re-scaled to the country-level so still represent comparisons to the wider eleven country region. Contact the authors if you would like to review pullout maps of other countries.

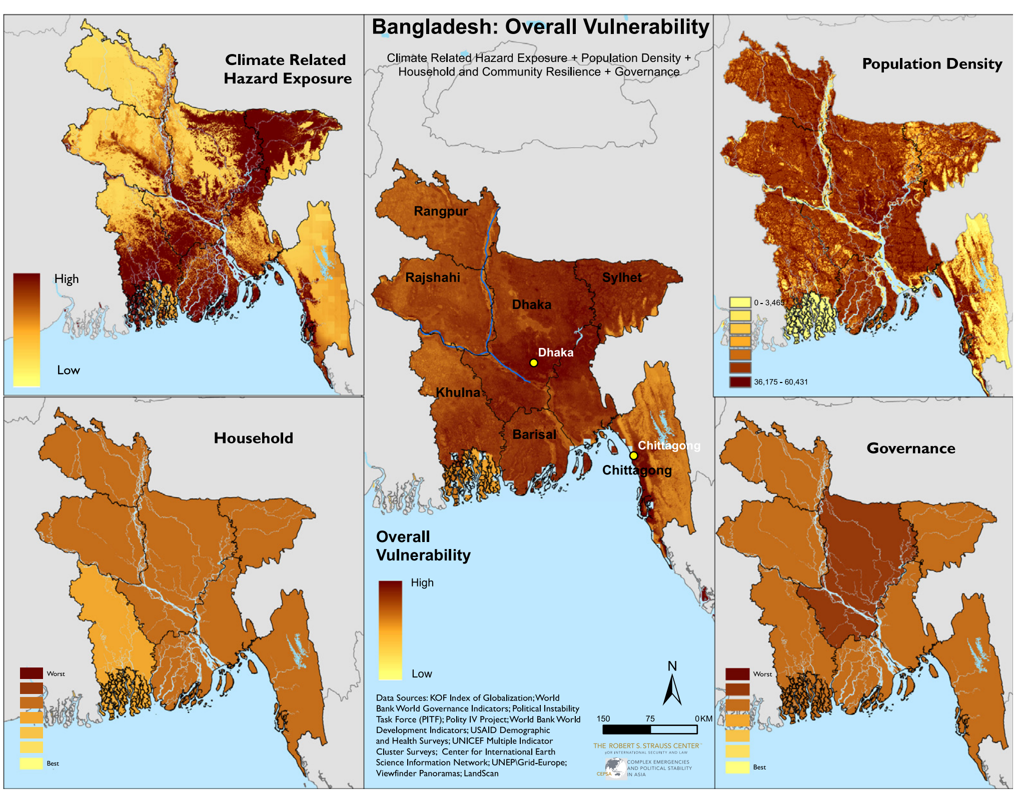


**Fig. A22.** Bangladesh.

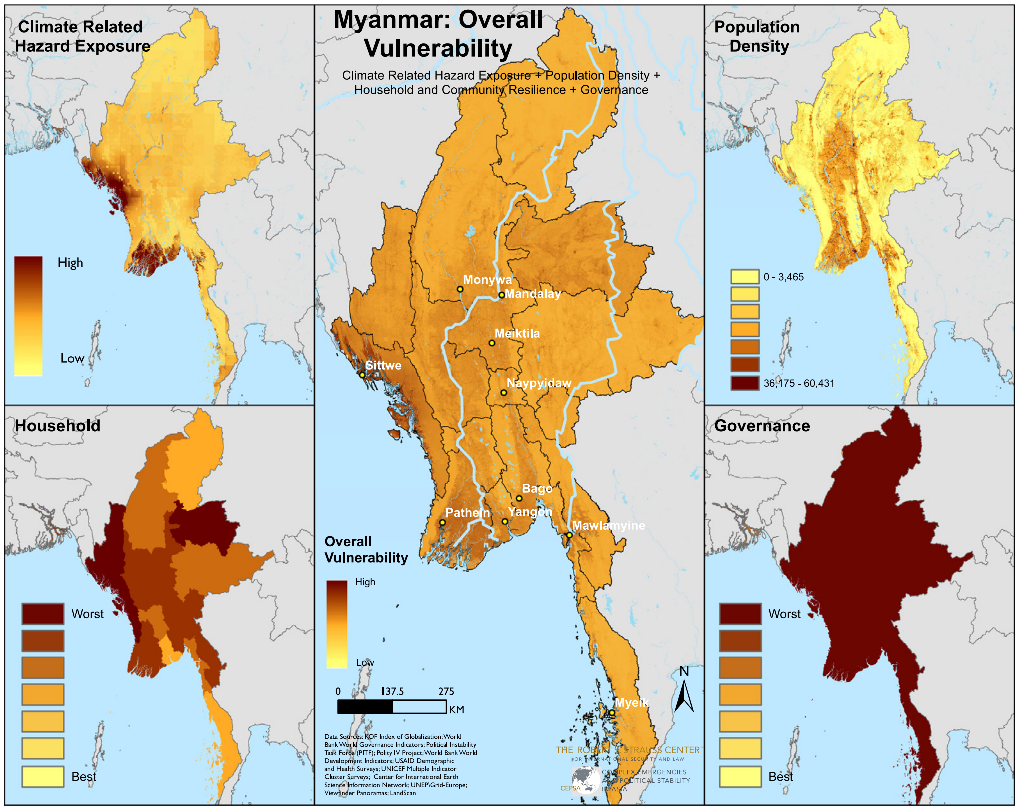


Fig. A23. Myanmar.

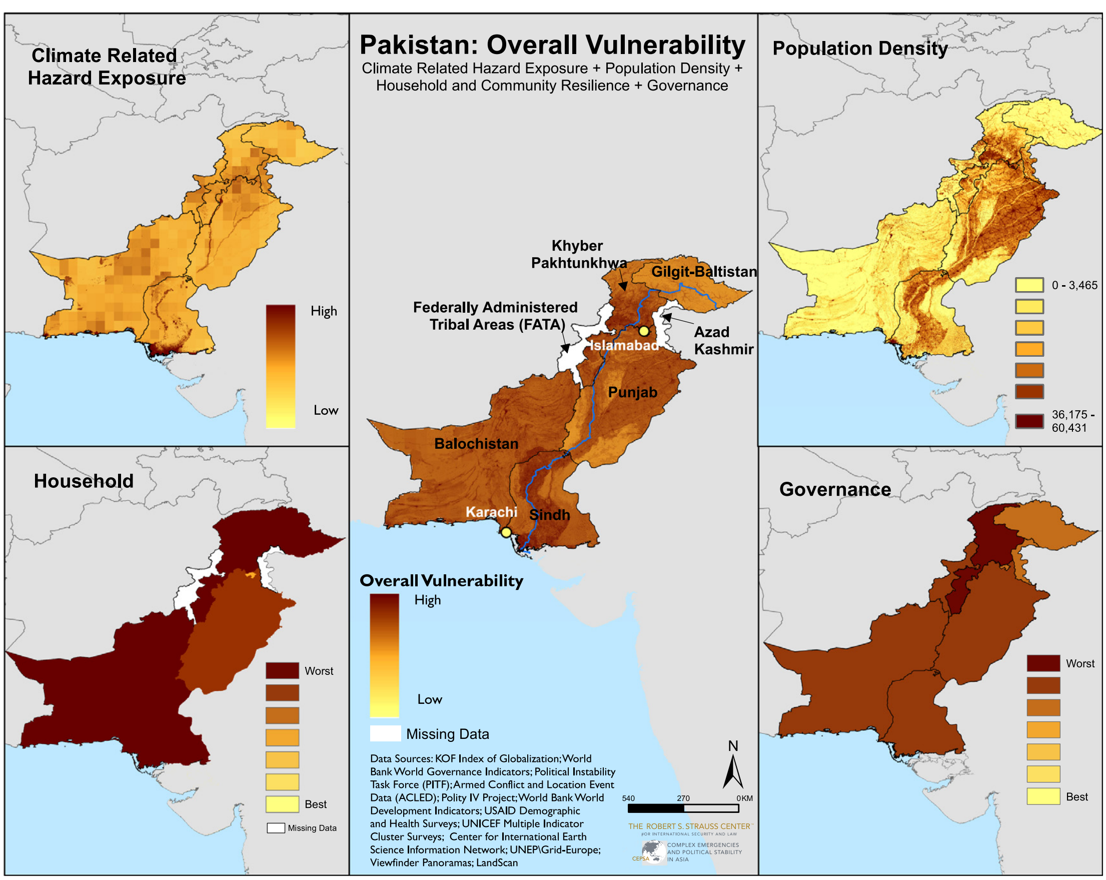


Fig. A24. Pakistan.

**Table A1**
Climate-related hazards data sources.

| Hazard Type (weight) | Indicator | Scale | Years of data used | Source |
|---|---|---|---|---|
| Rainfall scarcity (10%) | Number of months between 1980 and 2009 in which the 6-month accumulated rainfall was 1.5 standard deviations or more below the average for that calendar month over the previous 20 years. | 0.5 degree | 1981–2009 | Global Precipitation Climatology Centre |
| Aridity (10%) | Monthly coefficient of variation | 0.5 degree | 1981–2009 | Global Precipitation Climatology Centre |
| Cyclone Winds (20%) | Tropical cyclones average sum of windspeed (km per year) | 2 km × 2 km resolution | 1970–2009 | UNEP/GRID-Europe |
| Wildfires (20%) | Estimated frequency of events | 1 km × 1 km resolution | 1995–2011 | UNEP/GRID-Europe |
| Floods (20%) | Flood Frequency (per 100 years) | 1 km × 1 km resolution | 1999–2007 | UNEP/GRID-Europe |
| Inundation (Coastal elevation) (20%) | Low-lying coastal areas within 0 to 10 km above sea level | 3 arc second 1° × 1° (90 m) | | Viewfinder Panaromas |

**Table A2**
Population density data source.

| Variable | Indicator | Scale | Years of data used | Source |
|---|---|---|---|---|
| Population Density | Ambient population (average over 24 h) | Subnational at 1 km × 1 km resolution | 2013 | LandScan Oak Ridge National Laboratory |

**Table A3**
Household resilience data sources.

| Category | Indicator (weight) | Scale | Years of data used | Source |
|---|---|---|---|---|
| Education (25%) | Literacy rate, female (% of people ages 15–24) (12.5%) | National, CEPSA First Administrative District | DHS 2005, 2006, 2010, 2011, 2013; MICS 2010–2012; WDI 2011–2013 | Subnational data from DHS, MICS; national level data WDI |
| | School attendance, primary (% gross) (12.5%) | National, CEPSA First Administrative District | DHS 2005, 2006, 2010, 2011, 2013; MICS 2010–2012; WDI 2011–2013 | Subnational data from DHS, MICS; national level data WDI |
| Health (25%) | Infant mortality rate adjusted to national 2000 UNICEF rate (12.5%) | CEPSA First Administrative District | 2008 | Center for International Earth Science Information (CIESIN) |
| | Life expectancy at birth (years) both sexes (12.5%) | National | 2013 | WDI |
| Daily Necessities (25%) | Percentage of children underweight (more than two standard deviations below the mean weight-for-age score of the NCHS/CDC/WHO international reference population (12.5%) | National, CEPSA First Administrative District | DHS 2005, 2006, 2010, 2011, 2013; MICS 2010–2012; WDI 2011–2013 | Subnational data from DHS, MICS; national level data WDI |
| | Population with sustainable access to improved drinking water sources total (%) (12.5%) | National, CEPSA First Administrative District | DHS 2005, 2006, 2010, 2011, 2013; MICS 2010–2012; WDI 2011–2013 | Subnational data from DHS, MICS; national level data WDI |
| Access to Healthcare (25%) | Nurses per 1000 people | National | WDI 2004, 2010, 2011, 2012 | WDI |
| | Delivery in a health facility (% of births) (12.5%) | National, CEPSA First Administrative District | DHS 2005, 2006, 2010, 2011, 2013; MICS 2010–2012; WDI 2011–2013 | Subnational data from DHS, MICS; national level data WDI |

**Table A4**
Governance data sources.

| Category | Indicator (weight) | Scale | Years of data used | Source |
|---|---|---|---|---|
| Government Response Capacity | Government Effectiveness (20%) | National | 2009, 2010, 2011, 2012, 2013 | WDI |
| Government Responsiveness | Voice and Accountability (20%) | National | 2009, 2010, 2011, 2012, 2013 | WDI |
| Political Stability | Polity Variance (10%) | National | 2005–2014 | Polity IV Project |
| | Number of Stable Years (as of 2014) (10%) | National | 1950–2014 | Polity IV Project |
| Openness to External Assistance | Globalization Index (20%) | National | 2011 | KOF Index of Globalization |
| History of Violence | Subnational conflict events (20%) **OR** | CEPSA First Administrative Division | 2015 | Armed Conflict Location and Events Database (ACLED) |
| | Subnational atrocities (20%) | CEPSA First Administrative Division | 1997–2015 | Political Instability Task Force (PITF) |

**Table A5**
Discrepancies in EM-DAT data**.**

For example, when we received data from EM-DAT for 2014, CRED provided us with an updated version of the earlier data. For our study area, we found the following events had changes in the affected and death totals:

1. 2005821_NPL – change in number killed (18 in the new version, 0 in the old version)
2. 2009429_IND – increase in total affected (4,100,000 in the new version, 2,000,000 in the old – a difference of 2 million) and change in total killed (355 in new version, 300 in old – difference of 55)
3. 2010191_LKA – total affected increased by 531, 072 (606072 in new version vs. 75,000 in old) and an increase of 8 in total killed (from 20 to 28)
4. 2010373_IND: increase in total affected from 405 to 12,725 (increase of 12,320) (no change in # killed)
5. 2010693_IND: no change in total affected, but a 22 person increase in total killed (from 0 to 22)
6. 2012589_NPL: no change in total affected; a 3 person decrease in total killed (from 14 to 11)

CRED suggested that events had been revised due to new information sources and that they are part of a group on Integrated Research on Disaster Risk that is seeking to harmonize reporting standards on disaster risk along with Munich Re and Swiss Re which are other major information collectors.

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